AVIATION ENGINES

JOHN C. CHADWICK
LIEUT. (J.G.) U.S.N., R.F.

EDWIN N. APPLETON INC.
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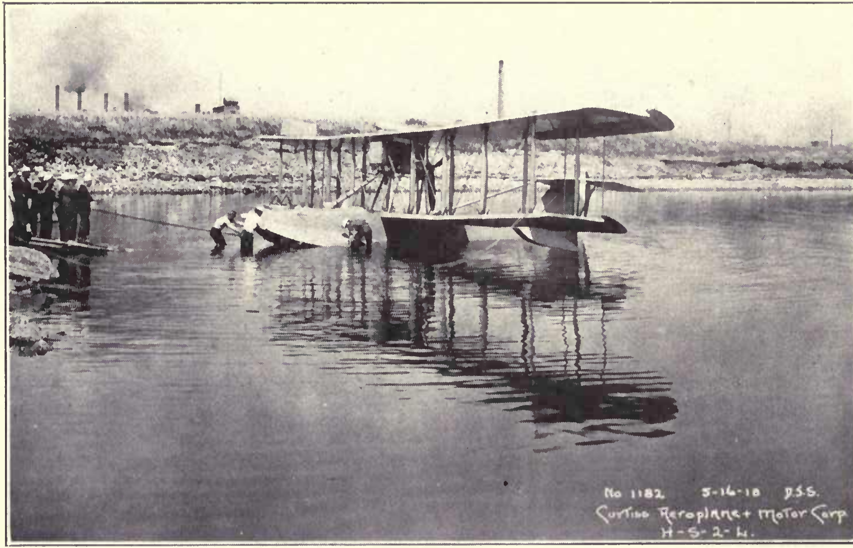

U. S. NAVAL FLYING BOAT—MODEL H-S-2-L
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NEW YORK

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CONTENTS

PREFACE

IN writing this book the author has endeavored to set forth the underlying principles of the Internal Combustion Engine as used in Aviation. The actual engines discussed are those that were used most widely by the United States Naval Aviation Corps during the recent war. They may be taken as very representative and highly efficient engines covering the field of American aviation in general at the present time. The Rotary Engine is not discussed, since its use was discontinued by our Navy, although it was widely used in light foreign planes, particularly those of French design.

The author has endeavored to set forth in non-technical language and without the use of mathematics, the main features of the principles employed in any internal combustion gasoline engine, and show their adaptation, in the three engines specifically discussed: the Liberty, Curtiss model 0XX, and Hispano Suiza.

The purpose of this book is to give anyone desiring to operate an airplane, a fundamental understanding of engines as used. It is founded on the course of instructions as given at the U. S. Naval Aviation Detachment, Massachusetts Institute of Technology, in Training Pilots for service. It is not intended for purposes of design, criticism or recommendation, but simply for instruction of the average individual, assuming he knows nothing of a gas engine.

For books pertaining to the mathematics of design, the author recommends:

Judges—"High Speed Internal Combustion Engines."
"The Gasoline Motor," by P. M. Heldt.

AVIATION ENGINES

INTRODUCTORY

Engines used in Aviation are all of the internal combustion type. By internal combustion is meant that the combustion or burning of the fuel takes place in the engine itself. The fuel used is gasoline (hydro carbon), and when mixed with air becomes highly explosive.

The mechanical parts of the engine consist of a cylinder, piston, connecting rod and crank shaft. The explosive mixture is drawn into the cylinder, one end of which is closed by the cylinder head, and the other end plugged by the piston. The explosive mixture is ignited by an electric spark and the expansion of the burning charge causes the piston to move down in the cylinder, just as the charge of powder in a gun causes the projectile to move down the barrel of the gun. As the motion desired to turn a propeller (which is used for the propulsion of the aeroplane) is rotary, the travel of the piston is converted into rotary motion by connecting the piston to a crank shaft, with a connecting rod. The motion of the piston then becomes reciprocating, up and down in the cylinder.

An internal combustion engine is, therefore, an engine that obtains its power from the rapid combustion and consequent expansion of some inflammable gas; and must have, in addition to the parts named above, ports and valves, whose opening and closing are so controlled as to admit the explosive gas into the cylinder and to expel the burnt gas. The degree of heat generated by the explosion of a charge is extremely high—in fact higher from the melting point of some metals, and it can

therefore be seen that the continued series of explosions would soon cause the engine to become heated to such an extent that it could not operate. It is therefore necessary to keep the temperature of the engine within safe working limits, and for this purpose a cooling system becomes necessary. The engine must be very carefully oiled, and for this purpose a lubricating system is necessary. As the fuel used is hydro carbon, a device must be used to convert the hydro carbon into a combustible gas. The device is called a carburetor and is referred to as the carburetion system. After the gas had been introduced into a cylinder, some means for igniting it must be provided in order that it may explode. This apparatus is called the ignition system. It can be seen from the above that there are four systems that are absolutely necessary in the construction of an internal combustion engine.

NOMENCLATURE

There are of course a great many parts to an engine besides those mentioned or alluded to in the introductory. The names of the various parts are in the most part self-explanatory.

It has been shown that it is necessary to have a cylinder in which the explosion and expansion of gases may take place, and in which the piston may travel.

It is necessary to have an intake valve and port so that incoming gases may be admitted properly to the cylinder. This makes necessary an intake manifold, or pipe, for conducting the gases from the carburetor to the intake port. Likewise it is necessary to have an exhaust valve and port, and in many cases an exhaust manifold to carry away the exhaust gases.

The piston must then be fastened to the connecting rod. This is done by means of the piston pin and, in order that steel may not meet steel, a fine bronze or brass sleeve is placed inside the hole of the upper end of the connecting rod. This is

known as a bushing. The lower, or big end of the connecting rod, is then fastened to the crank shaft. Again so that steel surfaces will not be in contact a bearing of softer metal is used. In this case, for ease of assembly and because of the larger surface, a bronze or brass shell, which is split, is lined with babbit or white metal and provides the rubbing surface. This is known as the connecting rod bearing.

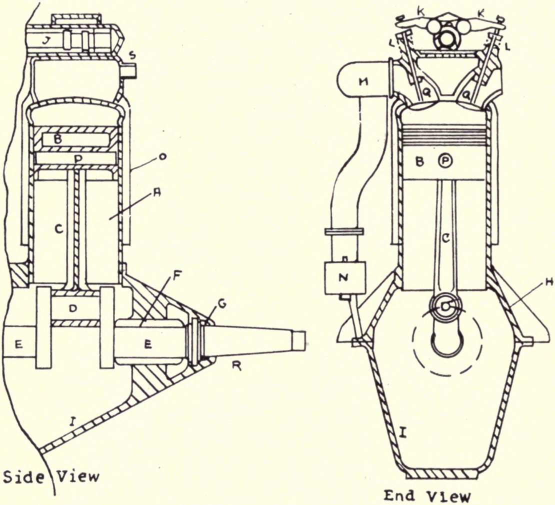
The crank shaft is the revolving part of the engine and consequently it must be supported. This is done by means of bearings placed in webbing of the crank base, and these bearings are known as main bearings. The crank shaft receives its power from the piston and connecting rod. Consequently it must have offsets or throws so that the heretofore straight line motion may become rotary. The part of the crank shaft which rests in the main bearings is known as the journal. The part to which the connecting rod is attached is called the crank pin and the parts connecting the two are called the cheeks.

Now it is necessary to have the valves actuated at the proper moments. This is done primarily by means of the cam shaft. This is a shaft upon which cams or eccentrics are placed. The shaft revolves, being geared to the crank shaft. Then when the high part or toe of the cam hits the lever or valve actuating mechanism, the valve is forced off its seat and remains open as long as the high point of the cam stays in position. The valve is opened always against the action of a spring, which closes it as soon as the cam is in a position to permit.

Following is a summary of the important parts of an engine. A glance at the accompanying cuts will show their assembly and co-ordination.

Cylinder: That part of the engine in which combustion and expansion occurs; and in which the piston reciprocates.

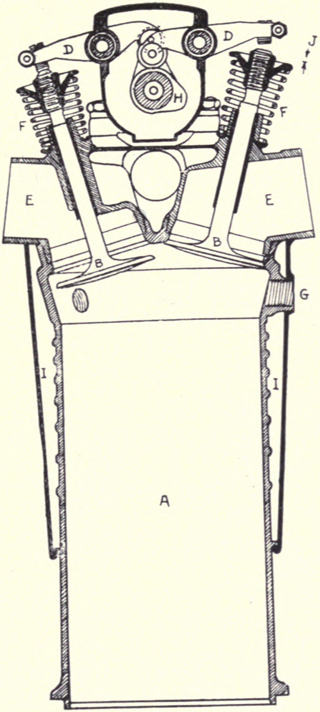
Valves and Valve Ports: Located in cylinder head to allow control of incoming and exhaust gases.



Cross Sections.

A- CYLINDER
B - PISTON
C - CONNECTING ROD
D - CRANK PIN
E - JOURNAL
F - MAIN BEARING
G - THRUST "
H - CRANK CASE
I - SUMP
J - CAM SHAFT

K - ROCKER ARMS
L - VALVE SPRING
M - INTAKE MANIFOLD
N - CARBURETOR
O - WATER JACKET
P - PISTON PIN
Q - VALVE.
R - CRANK SHAFT
S - WATER MANIFOLD CONNECTION



A—Cylinder. D—Rocker Arms. F—Valve Springs.
B—Valves. E—Valve Ports. H—Cam.
I—Water Jackets. J—Valve Clearance.

Piston: That part upon which expansion acts, causing downward action.

Connecting Rod: Connects piston to crank shaft, thereby converting reciprocating motion into rotary motion.

Crank Shaft: That member which receives rotary motion from the connecting rods and transmits it to the propeller either direct or through gearing.

Crank Case: Housing which furnishes a means of support for the crank shaft and cylinder.

Sump: Lower part or apron for the crank case, deriving its name from the fact that it is very often the oil reservoir.

Cam Shaft: Prime mover for the valve operation.

Timing Gears: Gears by means of which the proper speed of rotation is transmitted from the crank shaft to the cam shaft.

Rocker Arm: Lever mechanism for opening the valve.

Valve Spring: Spring for closing the valve.

Intake Manifold: Pipe or passage through which gases are drawn into cylinder.

Water Manifolds: Pipes through which water is distributed to and from cylinders.

Thrust Bearing: A ball-bearing that receives the push or pull of the propeller.

DEFINITIONS

Cycle of Operations: Series of events which occur in an engine from one intake stroke to the next.

Top Dead Center: Uppermost point of piston travel.

Bottom Dead Center: Lowermost point of piston travel.

Bore: Inside diameter of cylinder.

Stroke: Distance travelled by piston from top to bottom dead centers.

Piston Displacement: Generally referred to as meaning the total piston displacement of an engine, which is the volume

of the space displaced by the piston in one stroke times the number of cylinders.

Back Fire: Pop back or explosion in intake manifold or carburetor. Caused by improperly seated intake valve or mixture too lean. Causes a great many engines to catch fire and is a dangerous condition.

Back Kick: Rotation of the engine in wrong direction, caused by pre-ignition, or spark advanced too far. Dangerous especially when cranking by hand.

After Firing: Is the engine running after the switch has been cut, and is due to carbon particles in the combustion chamber or overheating. All aviation engines will continue to run after the switch has been cut unless they are allowed to run slowly for a few minutes and cool. After firing is very injurious to the engine and very often results in the breaking of timing gears, and other parts.

Idling: When an engine is running at a low speed (200 r.p.m. to 800 r.p.m., according to the make of engine) it is said to be idling.

Contact: Ignition switches in the starting position, throttle nearly closed ready for starting.

Off: Ignition switch in off position.

Throttle open: Throttle controls in wide open position, for purpose of drawing in a charge of gas for starting.

Spark retarded: Spark controls at point of extreme retard.

PRINCIPLE OF OPERATION OF A FOUR-STROKE CYCLE ENGINE

It has already been mentioned that power is obtained from the explosion and consequent expansion of a gas, which is the mixture of gasoline and air. Obviously it is necessary to clean the burned gas out of the cylinder when its power has been utilized. Also it is necessary to admit and draw a new charge into the cylinder.

There also is another important matter to be considered, namely, that all possible power must be obtained from the expanding gas. It has been found that by compressing a charge before igniting it the power derived will be vastly increased. Consequently there is still another item to be considered and which must be performed in the cylinder, viz.: compression.

From the foregoing it can be seen that it is necessary to go through four distinct operations to obtain one power impulse. Gas must be taken in; this gas must be compressed; power or work can then be derived from the ignition and expansion of the gas; and then the burned gases must be expelled.

All of these operations in a four-stroke cycle engine are performed by four strokes of the piston. Bearing in mind the fact that the piston is attached to the crank shaft by the connecting rod it will be seen that the crank shaft consequently makes two revolutions in this time. The four strokes necessary to complete one cycle then are:

1—Intake,
2—Compression,
3—Power,
4—Exhaust.

Consequently there is but one impulse per cylinder to every two revolutions of the crank shaft. Practically all aviation engines used at present operate upon this principle.

It may be noted here also that there is a point of uppermost travel and a point of lowermost travel for the piston at the beginning and end of each stroke. The uppermost point is known as Top Dead Center or just Top Center. Likewise the lowermost is Bottom Dead Center or Bottom Center.

The cycle of operations begins with the piston in the uppermost position in the cylinder. At this point a valve putting the cylinder in communication with the carburetor opens. The piston then travels down in the cylinder drawing in a charge of gas from the carburetor. When the piston reaches the end of its downward stroke, the valve closes; the cylinder

is then closed and the piston on the following up stroke compresses the charge and, at approximately top center, a spark occurs in the cylinder, igniting the charge; the piston is then subjected to the pressure of the burning, expanding gas, and is forced down in the cylinder; this is the power stroke. At the end of the power stroke the piston is again at bottom center. At approximately the end of the power stroke, another valve opens a port communicating with the atmosphere, and the piston on the next up stroke forces the burnt gas out of the cylinder, and this valve closes at approximately top center. The engine has then completed one cycle and is ready for the next.

Beginning with the piston at top center, the cycle of events, piston and valve movements can be followed thus:

Event	*Piston Stroke*	*Position of Valves*
1. Intake	1. Down	Intake valve open
2. Compression	2. Up.	Both valves closed
3. Power	3. Down	Both valves closed
4. Exhaust	4. Up	Exhaust valve open

VALVE LOCATION

Valve location has a great deal to do with the power output of an engine. In early practice, valves were located in pockets at the side of the cylinder head proper. Cylinders of this character come under two main headings. Where the exhaust valve is on one side and the intake on the opposite side the cylinder is termed "T" head. Where the exhaust and intake valves are both on the same side, the cylinder is termed "L" head. Both the above types have disadvantages because of the pocket formation, which hinders scavenging and power development. In the above cases the valves are operated by simple adjustable lifters transmitting the cam action to the valve stems.

In later practice the "L" head and "T" head have practically given way to the "I" head, in which the two halves are located directly in the head of the cylinder proper and operate

downward. In this type of cylinder the valves are operated by means of an overhead cam shaft with rocker arms; or if the cam shaft be located in the crank case, by means of a system of pushrods and rocker arms.

A rocker arm is simply a lever, pivoted near the middle, one end riding on the cam surface and transmitting the cam action to the valve stem by means of the other end. The part which comes in contact with the valve stem is called the tappet. It is usually in the form of a small bolt so that it may be adjustable. This is necessary to give valve clearance or a clearance between the valve stem and the tappet. Valves are subjected to high temperatures and therefore must expand. It is necessary to allow for this expansion. If no valve clearance were allowed expansion would take place and the valve would be held open, or off its seat, too long or all altogether. This would result in loss of compression and consequent loss of power. It may then be seen that valve clearance is very important and must be kept adjusted. Valve clearances differ with various engines, but are always specified by the manufacturer. Usually the exhaust valve clearance will be the greater since this valve is subjected to greater heat than is the intake. It is just as important for proper operation not to have too much valve clearance since this would allow the valve to open late and close early.

To insure against loss of compression the valve must make a gas-tight fit on its seat. To accomplish this, valves are "ground in," using a grinding compound of emery or some hard substance, so that the seat on both valve and port will be symmetrical and perfectly smooth.

PROPELLER DRIVE

The method of driving the propeller depends upon the running speed of the engine. The speed at which the propeller may efficiently be driven is limited to a rather narrow range,

varying ordinarily from 1100 to 1500 r.p.m. It has, however, been found practical to operate especially designed and constructed propellers at speeds as high as 1800 r.p.m. This, however, is done at some sacrifice to efficiency. The enormous centrifugal force developed by high speed rotation is of course one of the main limiting factors, but the even more serious one is the slippage and consequent efficiency drop occurring at high speeds. Where the engine speeds remain below 1600 to 1800 r.p.m. the propeller will usually be driven by direct attachment to the crank shaft itself, by means of a hub, keyed or shrunk on and secured by lock nuts.

There is, however, a constantly increasing tendency toward engines of higher speeds in order to take advantage of the consequent reduction in weight per horse-power developed. The output naturally is augmented as the speed increases and if the weight of the engine can be maintained about constant, or only slightly increasing, the advantage is readily apparent. This tendency is becoming more and more prevalent and makes necessary the geared down propeller drive. By employing a propeller drive shaft geared to the crank shaft, it is perfectly possible to surmount the difficulty and maintain efficient propeller speeds by properly regulating the gearing. At the present time gearing has been so greatly improved that the consequent drop in horse-power output, through its employment, is practically negligible as is the consequent increase of weight which it causes.

The thrust of the propeller is transmitted through the engine to the longerons of the fuselage. It is taken up by the crank case from the crank shaft by a ball thrust bearing at the propeller end of the shaft.

It is most important to keep the propeller lined up at all times, otherwise severe and dangerous vibration will result. The most common method of checking propeller allignment is to measure from a fixed point on the engine to a certain point

on the propeller surface, the propeller blade being in the vertical position. Bring the other blade into the same position and measure the corresponding distance. This should check within 1/32″ to 1/16″. If the error is greater it can be counteracted by means of the hub bolts. If propeller vibration is noticed and lining does not correct it, change the propeller, as propellers have been known to be inherently wrong and yet appear to be as specified in every way.

MULTI-CYLINDER ARRANGEMENT

From the events of the four-stroke cycle it will be seen that there is only one power application on a piston during the four strokes. In other words, the power stroke must furnish energy enough to carry the engine through three dead strokes and also to perform useful work. Realizing this, it is simple to see that the one cylinder engine will deliver power in a very spasmodic manner.

It would be perfectly possible to build a one-cylinder motor of enormous horse-power, but the explosions would be so tremendous and occurring at such a distance apart, that not only would the engine have to be enormously heavy, but vibration would be such that it would be utterly useless.

One great advantage of the electric motor is that power is applied to the rotating shaft throughout its entire rotation. Then why not break up the dead intervals of the one-cylinder engine by utilizing several cylinders whose combined power would approach a steady application instead of coming spasmodically? This would have numerous advantages. Comparing a one-cylinder engine to an engine of several cylinders, but the same horse-power, it is easily seen that the power delivery will be more constant, and terrific strains will be eliminated, due to the more constant succession of power strokes. This means that vibration will be reduced, weight of parts will be

reduced and consequently internal friction, all of which will tend to increase the useful work output of the engine.

With these thoughts in mind, it is clear why the one-cylinder arrangement gave way to the two, and the two to the four and six, and the four and six to the eight and twelve. For naval aviation purposes four cylinders is the minimum number used. Where fours and sixes are used the cylinders are arranged vertically in a straight line and a crank shaft constructed so that connecting rods from each cylinder may be attached to each crank throw. In these engines the crank shafts have as many throws as there are cylinders and are so constructed that power is applied evenly throughout each revolution.

If eight cylinders are to be used it is obvious that their arrangement, vertically in a straight line, would necessitate a very long crank shaft, and the engine would take up great space. It is possible to obviate this by splitting the cylinders into two sets and placing these sets, or banks as they are commonly termed, on an angle with each other. Such an engine is called an eight-cylinder V-type engine because of the V angle between banks. With this arrangement it is then seen that the space occupied is much more compact. Also the necessity of a very long crank shaft is overcome, and by regulating the angle between banks, the ordinary four-cylinder crank shaft is used, having two connecting rods, one from each bank, fastened to each crank pin. The same principles are applied to the twelve cylinder engines, except that the banks consist of six cylinders each and again, by regulating the angle between banks, the six-cylinder crank shaft is used. The regulation of this angle depends upon the firing interval desired. If the interval is to be equal, the angle between banks must equal the firing interval. If the angle is of any other value the firing intervals will be unequal.

COOLING

The combustion of the explosive mixture inside the cylinder of an aviation engine generates intense heat; this continued generation of heat would soon render the engine inoperative if the cylinders were not cooled in some way. There are two ways of doing this, with air or with water. The principle of both systems is to conduct the excess heat of combustion rapidly enough away from the cylinder walls to prevent damage by burning away the oil and causing the pistons to seize.

Water Cooling: Heat is dissipated in a water-cooled engine by surrounding the cylinder wall with another wall, and by circulating water through the space in between the two. The external wall is called the water jacket. Water jackets around the cylinders can be formed in various ways. If the cylinders are of cast iron or cast aluminum, the jacket is usually cast integral with the cylinder. Sometimes the jacket is made of sheet metal, brazed or welded to the cylinder. This latter type of jacket is used when the cylinders are of steel, as in the Liberty engine. Only a small quantity of water can be carried in an airplane, hence the hot water which has just cooled the cylinder must itself be cooled and used over again.

RADIATORS

The hot water from the water jacket is cooled by air in much the same manner as an air-cooled engine cylinder, that is, by radiation and conduction. The device for this purpose is called a radiator, and consists of a series of very thin water passages around which air can circulate. Circulation of air is provided by the motion of the plane through the air.

WATER CIRCULATION

The water, in being used over again, is circulated through the water jacket and then through the radiator. The direction

of circulation is determined by the fact that heated water tends to rise and cooled water to fall. Hence, the cooled water from the radiator is introduced at the bottom of the water jacket, and the hot water from the top of the water jacket is led off to the top of the radiator. This natural tendency for heated water to rise is sufficiently strong to cause an actual circulation of water around the cooling system, provided the water passages are large, and the system full of water. This is called thermo-syphon circulation. It is customary on aviation engines, however, to make the water circulation positive by means of a pump acting in the direction of the thermo-syphon action. By this means less water is required and the cylinder temperature can be more closely controlled.

WATER PUMPS

The kind of water pump most commonly used is the centrifugal type, consisting of a rotating impeller or paddle wheel in a casing. Water is led into the center of the impeller and is thrown out to the edge by centrifugal force. The outlet is at the rim of the casing.

OPERATION OF COOLING SYSTEM

The temperature of the water in the cooling system is an excellent indication of the condition of the cooling, lubrication, carburetion and ignition systems, as there are troubles which can occur in all these systems which cause overheating. Hence a thermometer of some kind with a dial on the cockpit instrument board is used to indicate the water temperature. Excessive water temperature should lead to an investigation of its cause.

It is impossible to lay too much stress upon the importance of this instrument. It is the pulse of the cooling system. The pilot must be familiar with its proper recordings and should train himself to pay particular attention to it at all times. If

this is done trouble may very probably be remedied before it becomes dangerous. The bulb of the water temperature meter is usually located in the outlet header of the water system, and indicates the temperature of the water that is leaving the cylinder jackets, which is the maximum temperature of the water in the system.

LUBRICATION

Any internal combustion engine has a great many sliding and bearing surfaces. Friction is ever present at these points and must be minimized for efficient operation. Not only does friction cause loss of useful power, but it also generates heat. To minimize both these effects some good lubricant must be used, so that an oil film may be established between sliding and bearing surfaces. This metal to metal contact will be avoided and friction consequently reduced.

In all naval aviation engines oiling is sent to the various parts by pressure maintained by a pump usually of the rotary gear type. The oil being under pressure is sent through tubes or ducts to the various bearing points.

It may then be seen that oiling troubles may be detected in two ways, by temperature and also by pressure. A gauge is provided for recording both these. These are the pulses of the oiling system and here again the pilot must observe the temperature and pressure of the oil at all times. Sudden increases or drops in either should be investigated at once.

Oil may be carried in the sump of the engine or in outside reservoirs at a level above the oil pump. In the latter case the engine is said to have a dry sump. This type is advantageous for two reasons. The oil is well cooled by being circulated through the outside reservoir and there is no danger of oil from the sump flooding the cylinder when the machine is at a heavy angle. There is a return pump provided to take oil from the sump and return it to the reservoir.

In the average pressure system oil is forced from the pump through a strainer to the crank shaft, camshaft, pump and magneto drive shaft bearings direct. However, oil must be conveyed through passages drilled in the crank shaft to the crank pin bearings on account of their rotation. From here the cylinder walls, piston pin bearing, etc., may be lubricated in two ways. Since the big end connecting rod bearings must have clearance, oil will be forced out due to the pressure. This will be beaten into a fine mist by the revolving crank shaft and thrown upwards, lubricating cylinder walls, piston pin, etc. This type of oiling is called Force Feed. In some engines this is not considered positive enough. Accordingly a duct is run from the big end connecting rod bearing, along the rod, to the piston pin. This supplements the force feed system and is called a Full Force Feed system.

Oil is transferred under pressure from a stationary bearing to the inside of a rotating shaft by a hole in the shaft which registers once every revolution with the supply lead to the bearing. This method is used to carry the oil from the crank shaft bearing into the hollow crank shaft and from the crank pin to the connecting rod, and thence up the connecting rod duct to the piston pin; this latter being in the full force feed system. Only a small portion of the oil is actually consumed, the rest returns to the sump, and thence to the reservoir, if the sump is of the dry type, and is used over again.

Particular attention must be given to the oil temperature. It must be moderate so that the oil may retain good lubricating qualities. Here again is another advantage of the dry sump since this system also serves to cool the oil. It is just as necessary to watch oil pressure, which must be maintained within certain limits for efficient lubrication. In most cases there is a Pressure Relief Valve provided by which pressure may be regulated or at least limited. This consists simply of a valve held seated in some main oil passage by a spring set to withstand a certain pressure. This limits maximum pressure,

which is necessary to prevent flooding of the engine with too much oil. The oil pressure meter must be carefully watched. Very often serious accidents may be averted by paying attention to sudden pressure drops which are always an indication of trouble.

Oil loses its body after being used, also it collects fine particles of metal from bearings, etc. It is therefore poor economy to use oil too much. It should be changed often. More often at first in a new motor, since the wear on bearings will be greatest at first. When the motor is torn down all oil leads should be carefully cleaned out to prevent collection of anything which would tend to form obstructions.

CARBURETION

Carburetion is the process of saturating air with hydrocarbon in the correct proportion for a combustible mixture. The most important function which a carburetor has to perform is to supply to the engine, under all conditions of load, speed and throttle opening, a mixture of such proportions of gasoline and air as will result in the most complete combustion and maximum power.

It has been found that the correct mixture should consist of approximately fifteen parts of air to one part of gasoline by weight.

The Zenith carburetor is being widely used for aviation work because of its simplicity, as mixture compensation is secured by a compound nozzle arrangement that gives very good results in practice. To understand the carburetor we will have to consider, first, the simple type of carburetor.

A simple carburetor consists of a single jet or nozzle placed in the path of incoming air. The gasoline is fed to this jet or nozzle by a float chamber. It is natural to suppose that as the suction of the engine increases the flow of gasoline and air will increase in the same proportion. This, however,

is not the case. There is a law of liquid bodies which states that the flow of gasoline from the jet increases under suction faster than the flow of air, giving a mixture which grows richer and richer as the engine speed increases. A mixture containing much more gasoline at high speed than at low. It is easily seen from this that the simple type of carburetor would give very unsatisfactory results and could not be used. The common method used to correct this defect is to attach auxiliary air valves which add air and tend to dilute the mixture as it gets too rich. These auxiliary air valves, however, are very hard to gauge and, having delicate springs, get out of order very easily, and are nothing more than a makeshift.

The Zenith system of compound nozzle depends upon the compensating effect of one jet giving a leaner and leaner mixture, as engine speeds increase, upon the jet of the simple carburetor as described above. To do this the principle of constant flow is used. Accordingly a device allowing a fixed amount of gasoline to flow by gravity into a well which is open to the air, is made use of. One jet may then be connected direct to the float chamber. This is known as the main jet and naturally gives a richer and richer mixture as engine speeds increase. Another jet may now be placed around the main jet, connecting with the atmospheric well. This is known as the Cap Jet. The constant flow device (the compensator) then delivers a steady rate of flow of gasoline per unit of time, and as the suction of the motor increases more air is drawn in while the amount of gasoline remains the same and the mixture grows poorer and poorer. By combining these two types of rich and poor mixture jets the Zenith compound nozzle was evolved.

One jet counteracts the defects of the other, so that from the starting of the engine to its highest speed there is a consant ratio of air and gasoline to supply an efficient mixture. In addition to the compound nozzle the Zenith is equipped with an idling device. When the throttle is nearly closed the compound

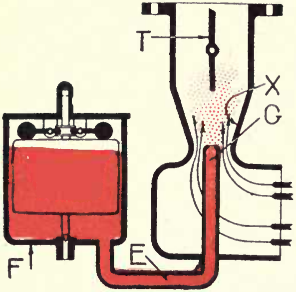


FIGURE 1

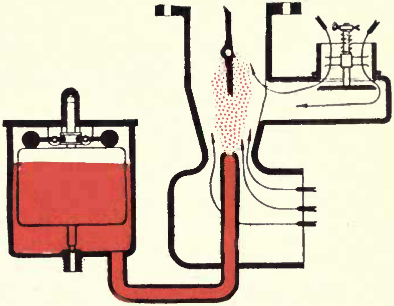


FIGURE 2

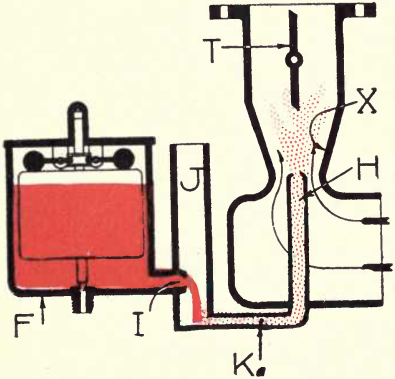


FIGURE 3

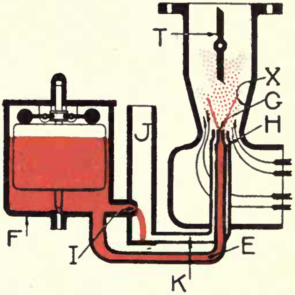


FIGURE 4

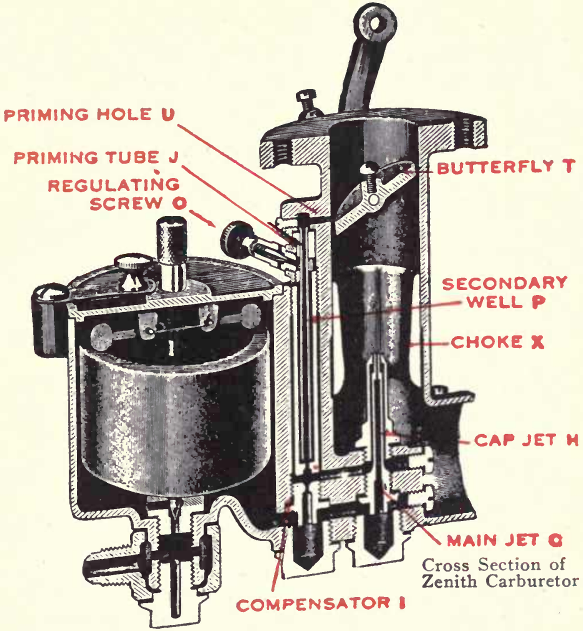


FIGURE 5

Explanation of preceding figures 1, 2, 3, 4, 5.

T. Butterfly valve (sometimes called throttle valve).
F. Float chamber.
X. Venturi (sometimes called choke).
G. Jet. (In Zenith Main Jet.)
J. Main well.
I. Compensator.
H. Cap jet.
E. Passage through which gasoline flows to main jet.
K. Passage through which gasoline flows to cap jet.

The arrows indicate the flow of air.

Figure 1 shows a simple type of carburetor, the jet G is placed in the path of incoming air, the suction of the jet is created by

the Venturi X, the smallest internal diameter of which is located at the opening of the jet. It has been explained that this type of carburetor would supply an increasingly rich mixture as the suction increased. The air valve shown in figure 2 was fitted in order to admit air above the jet and not increase the suction on the jet. This valve did not prove a success on aviation engines, for several reasons. The Zenith uses the compound nozzle as shown in figure 4. The main jet G supplies as mixture that grows richer and richer as the speed increases, and a mixture that grows leaner and leaner as the speed increases.

The action of the cap jet is shown in figure 3 as follows:

The compensator I, feeds gasoline into the main well J, which is open to atmospheric pressure, suction on the cap jet H, would draw this gasoline out of the main well J, but owing to the main well being open to atmospheric pressure, the flow of gasoline through the compensator I, would not increase, the suction on the compensator being relieved by the air held in the top of the main well. The mixture supplied by the cap jet would therefore grow leaner and leaner as the speed increased. This compound jet maintains a constant mixture of gasoline and air at all speeds.

Figure 5 shows a cross section of a complete Zenith carburetor, the butterfly valve T, is shown in the idling position, there being no suction on the jets, the main well will fill with gasoline to the level of the gasoline in the float chamber. The suction then comes on the priming hole U, and gasoline will be drawn out of the main well, through the priming tube J, this amount of gasoline being regulated by the size of the hole in the secondary well P, and the regulating screw O.

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nozzle gives no gasoline, but as there is considerable suction at the edge of the butterfly valve, gasoline is drawn through a small hole drilled in the body of the carburetor and connected to an idling jet which is submerged in the gasoline that is in the well.

A carburetor adjusted to supply a properly proportioned mixture at sea level will supply in increasingly rich mixture as the machine mounts to higher altitudes, due to the difference in temperature, density and quantity of oxygen in the air. To overcome this an altitude adjustment is used. In the ordinary Zenith this is simply a butterfly valve which may be opened by

the pilot allowing more air to enter the top of the mixing chamber, thus making up for the loss in density due to higher altitudes. This adjustment does not interfere with the suction at the jets to any extent, but simply admits more air.

The effect of altitude in carburetion is illustrated in the following paragraphs taken from an article written by the Zenith Carburetor Company:

"In regard to the necessity of changing jets in the Zenith Carburetor in the higher altitudes above sea level, we have no hard and fast rule governing the different sizes according to variation in elevation. The Zenith Carburetor varies so greatly from the air valve carburetor that the effect of altitude is very much less with this type of carburetor, due to the surface of the air valve, also the tension of the spring being very sensitive to the reduced atmospheric pressure. For instance, we have at sea level atmospheric pressure of 14.7 pounds per square inch; at 5,000 ft., 12.18 pounds; at 8,000 ft., 10.87 pounds; at 10,000 ft., 9.96 pounds; at 12,000 ft., 9.31 pounds.

"It will be very readily seen, with this great reduction in atmospheric pressure action upon spring and valve, it would be necessary to make this spring very much weaker, whereas in the Zenith Carburetor we have no valves or springs regulating the amount of air taken in. Therefore, very great differences in altitude have very little effect on the actual operation of the Zenith Carburetor.

"Just a little data on the effects of altitude in regard to the gasoline motor developing its rated horse-power.

"Air consists of two gases—oxygen and nitrogen—in the proportion of 1/5th oxygen and 4/5th nitrogen by weight. This proportion holds good all through the atmosphere from the bottom to the top. Oxygen is the element that supports combustion. Consequently, if we go to a higher altitude, where the air pressure is less, a given volume of air will not weigh as much as a similar volume at sea level. It will not contain as much oxygen.

"From this we see that a cylinder full of air at sea level will contain a greater weight of oxygen than the same cylinder on the top of a high mountain.

"Assuming the carburetor adjustment to be the best for efficient running at sea level, with altitude valve closed, it will be advisable to start opening the altitude valve at about 2,500 feet elevation and keeping it as far open as possible without reducing the engine r. p. m.

"Extensive test have shown that—above 5,000 feet elevation—change in engine power will be negligible, but that consumption of fuel will be reduced from 8 per cent. to 10 per cent. by operating the engine with the altitude valve open."

There is another general type of carburetor coming more and more into prominence known as the multiple jet type. Under this heading come the Miller and the Master. A number of jets are set in a straight line, and so arranged that the size of the jets increase progressively. The throttle valve is of the barrel type, which more nearly approximates the action of a variable venturi. On opening the throttle to speed up, the jets are uncovered progressively. In this way a very strong venturi action is centered at slow speeds over one or two small jets and as the speed is increased this action is decreased. The additional gas being provided by the remaining jets as suction reaches them. Carburetors of this type are simple in construction and easily maintained once they are regulated. This can be done only by a careful study of the engine demands and adaptation of suitable jets in accordance. One regulated they are singularly free from adjustments.

The Stromberg Company has recently developed a carburetor for aviation purposes which, on recent tests, has given excellent results.

The Stromberg carburetor maintains the proper mixture by what is known as an air-bled jet. Gasoline leaves the float chamber, passes the point of a high-speed adjustment needle, and enters a vertical channel or well. Air is taken into this

channel through the air-bleeder, or air adjustment. This air discharges into the gasoline channel through small holes and beats up the gasoline into a fine spray. This then enters through a number of jets into the high velocity air stream of a small venturi. There is a second or large venturi provided through which the mixture next passes. Since good excelleration requires a temporary enrichment, there is a reserve chamber or excellerating well provided which is concentric to and communicates with the vertical channel mentioned above. With the motor idling or slowing down, this well fills with gasoline and whenever the venturi suction is increased by opening the throttle, the level in the well goes down and the gasoline thus displaced adds to the amount entering the small venturi.

The carburetor is also provided with an idling device. In the center of the vertical channel, there is located a long tube which extends up the side of the carburetor, and has an entrance to the mixing chamber through a small hole at the level of the butterfly valve; when the throttle is closed, or nearly closed, gasoline enters through this small hole. The proper mixture is maintained by regulating the admission of air into the idling tube by an idling adjustment screw. This idling adjustment does not work after the throttle has been opened, so that the engine runs above idling speed.

There is still another type of carburetor which furnishes the proper mixture at all speeds by means of a variable venturi. Many models have been constructed using this idea but they are to the greatest extent still in experimental stages and so far are a great ways from perfection. The adoption of this principle would be ideal and there are several corburetors which attempt to approximate it in various ways.

EFFECTS OF IMPROPER CARBURETION

As already stated the problem of carburetion is to maintain the proper mixture at all engine speeds. There are numer-

ous effects which will give indications of an improper mixture. First let us consider the effects of a lean mixture; that is, a mixture in which there is too little gasoline per unit of air.

The lean mixture will, in the majority of cases, be made evident by back-firing or spitting back of the carburetor. The cause of this is that the mixture, containing too little volatile matter, will be slow burning, and some of it will still be burning when the intake valve opens on the next succeeding stroke. Naturally this will cause ignition of the gases in the intake manifold and a back-fire will result. This is very dangerous as fire is likely to result if the carburetor is not placed where it will be away from any gasoline drip which may have collected. A lean mixture being slow burning will expose more cylinder wall to heat than a proper mixture, and, therefore, it is said that overheating will result. There will be a tendency toward this, but it is generally conceded that this effect is neutralized to a great extent by the cooling effect of the additional air present in the mixture. Naturally an engine running on too lean a mixture will not develop the proper power.

A rich mixture is also slow burning. It, however, does not cause a back-fire but will cause an after-fire. It is naturally a heavier, more homogeneous gas than a lean mixture and consequently none of it is left in the cylinder after the exhaust stroke. Therefore, back-fire cannot occur, but a loud exhaust or after-fire will result.

Also, on account of slow burning, overheating will result, since more cylinder wall than should be is exposed to the burning gases and the cooling system will be over-taxed. Due to the greater amount of carbon present in the mixture, and its incomplete combustion, the formation of carbon will proceed more rapidly with its consequent detrimental results. A rich mixture will also result in loss of power.

An expert can tell by the color of the exhaust flame the exact condition of the carburetion system. The proper flame is almost an invisible blue, while a yellowish flame indicates a

lean mixture and a red flame, accompanied in bad cases by black smoke, a rich mixture.

ELECTRICITY AND MAGNETISM

Units:
Volt = Unit of pressure.
Amperes = Rate of flow.
Ohm = Unit of resistance.
Watt = Unit of power (Volts X amperes).

Resistance is the opposition that any material offers to the flow of an electric current.

A conductor is a metallic substance of low resistance that is used to conduct an electric current; viz: a coil of copper wire.

An insulator (non-conductor) dielectric any substance of such high resistance that *practically* no current can flow through it. (Glass, porcelain, rubber, etc.)

Magnetism is the invisible field of forces operating between the poles of a magnet, and in circular rings about a wire through which a current is flowing. This magnetic field exists in the form of *lines of force,* or *flux.* The permanent magnet is usually made in the form of a horse shoe, and is always used to furnish the magnetic field in a magneto. In a generator and in the battery type ignition, an *electro magnet* is used. This is *not* a permanent magnet, and only sets up a magnetic field as long as electricity is flowing through the conductor that is wound around its soft iron core.

INDUCTION

Induction may be taken to mean, in simple words and for present purposes, causing an electric current to exist. This may be accomplished in three ways:

1. Passing a conductor through a magnetic field or lines of

force, thereby causing the conductor to cut the field and inducing a voltage in it and current, if a closed circuit. That is, having a stationery field and a moving conductor.

2. Reversing the above condition, that is, having a stationary conductor, but a movable field.

3. Having both conductor and field stationary and inducing a current by changing field strength, that is, causing a change in the value of the flux.

IGNITION

After the gas has been compressed by the compression stroke, it must be ignited in order to furnish the expansion necessary to force the pistom down for the power stroke. A spark plug consisting of two electrodes, separated by an insulating material, is screwed into the combustion chamber of the cylinder. The two electrodes are separated at their ends or points by an air gap, and by causing an electric spark to jump this gap, the compressed gas is ignited. The electric current necessary to jump across the spark plug gap is furnished by the ignition system, which can be of the magneto or battery type.

The ordinary current furnished by a battery or generator is not of sufficient voltage or pressure to jump across the gap of the spark plug, and in order to raise the voltage of the battery or generator, an induction coil is incorporated in the ignition system, and supplies the high voltage current necessary to jump the spark plug gap.

If a conductor is coiled about a soft iron core, and current is caused to flow through the coil, the core will become a magnet, thereby causing a magnetic field to be established. The moment current ceases to flow in the coil the core ceases to be a magnet and consequently its magnetic field collapses. Now, if a second coil be wrapped about this first, the collapse of the magnetic field, caused by breaking the circuit of the

first coil, will induce a current in the second. This is the principal of the induction coil. The first coil which causes the core to be magnetized and de-magnetized, is called in the primary. The second or out coil is the secondary. Both are wound on the core, the secondary over the primary.

The primary coil consists of a comparatively small number of turns of coarse wire while the secondary contains a large number of turns of very fine wire. The desired result is to obtain high voltage or high pressure which will be capable of breaking down the resistance of the spark plug gap. Consequently, the induced or secondary current must be of high voltage or high tension. As it is impossible to get something from nothing the power or wattage of both primary and secondary circuits must be theoretically the same. Consequently, the secondary must be of low current value in order to allow the higher voltage value since wattage must remain constant.

It can then be understood why fine wire is used for secondary purposes. Simply because it will not be conductive to heavy amperage; in fact will make it impossible for heavy amperage to exist and the result, since wattage must be the same as in the primary, will be high voltage value.

Since the induced voltage is directly proportional to the ratio of the number of turns in the secondary coil to the number of turns in the primary, it may be easily seen why the secondary will consist of a large number of turns; bearing in mind that the desired result is high voltage.

Breaker Mechanism:

The intensity of induced voltage will also be greatly dependent upon the rapidity with which the secondary coil is cut by the collapsing field. That is, maximum voltage will be dependent upon maximum rate of change of flux. The most effective method of obtaining this result is to suddenly interrupt the flow of primary current, thus stopping the generation of lines of force by it, and changing instantaneously

the number of lines of force through the secondary from a maximum to zero. The device which interrupts the primary circuit is the Breaker Mechanism, consisting of two breaker points, one stationary—the other held in contact by a lever and spring. The cam acts on the lever causing these points to separate and break the primary circuit.

Condenser:

Current is flowing around the primary circuit at the moment of interruption by the breaker points, and due to its own inertia, it tends to keep on flowing and jump across the air gap created by the separation of the breaker points. If no provision were made to stop this condition, the induced or secondary voltage would not be as intense as possible. The reason for this would be that due to the leakage across the points the collapse of the magnetic field would not be abrupt. It has been pointed out that the more rapid the collapse, the more intense the induced voltage; hence this leakage must be stopped. Not only will the induced voltage be poor, but the breaker points will become badly pitted due to the arcing across the air gap created. This would make it impossible to keep the points clean, well surfaced and at correct adjustment, all of which would be decidedly detrimental. To overcome these defects a condenser is connected around the breaker points. A condenser is composed of alternate layers of a conductor and a dielectric, very often tin foil being used for the former and mica for the latter.

The alternate layers of the conductor are connected to opposite terminals of the device. Hence there is no path for current through the condenser, but it acts as a reservoir. When the breaker points separate, the current flows into the condenser instead of arcing across the points. When the condenser is fully charged it rapidly discharges in the reverse direction, thereby causing a sudden reversal of magnetic flux, and this condition continues, producing an oscillatory current

of very high frequency until the current value becomes so reduced that the action must cease. This oscillatory discharge has its effect on the secondary induction, the result being a prolonged spark assisting in overcoming the resistance of the spark plug gap and insuring better ignition. At times some of the dielectric substance will be punctured thus reducing the capacity of the condenser and making it necessary for part of the current to jump across the breaker points. Where pitted points are found the operator can be practically positive that the condenser is faulty. If, however, the condenser becomes entirely burned out, the result will be a short circuiting of the breaker points and no interruption of the primary, resulting in no ignition.

Breaker Point Adjustment:

In every ignition system there is a certain maximum distance of opening for which the breaker points are designed. They must be kept in adjustment so that the opening will always be correct. Suppose the opening prescribed is to be 0.020″ and the adjustment is faulty so that the opening permitted is above the net amount. Naturally it will take longer for the points to return to contact. This will result in a considerable lag at high engine speeds, and it is common to have this condition drag out to such an extent that ignition will fail for as much as one complete revolution. The result, then, of too great a gap, will be faulty ignition and consequently misfiring. If the opening is below the prescribed amount, the resistance of the air gap will reach a point where it will be below the resistance of the primary coil. Then when the condenser discharges, instead of going through the coil, the current will arc across the points, the result being the same as given by a faulty condenser. Again the result will be faulty ignition.

It may then be seen that correct breaker point adjustment is imperative for proper engine running.

Distributor:

The spark will jump across the spark plug gap when the current induced in the secondary is at a maximum value, in other words, when the breaker mechanism interrupts the primary current. Hence, the breaker mechanism must be timed to the engine so that the spark will occur at the proper time. If only one cylinder is to be ignited, the secondary wire can be led directly to the spark plug. However, when more than one cylinder is used, a device must be introduced to direct the high tension secondary current to the proper cylinder. This device is called a distributor, and consists of a rotating arm which touches one contact for each cylinder in succession. A wire leads from each contact to its cylinder. Hence, when the primary circuit is broken, a spark will be flashed in the cylinder with whose segment the distributor arm is making contact.

Ground:

In order to simplify wiring, one end of both the primary and secondary circuits is attached to some metal part of the engine. Thus the metal of the engine serves as one wire of the circuit, and is known as the "ground."

Primary Circuit:

The primary circuit consists of a source of current, for example, a storage battery, with one terminal wired to the ground, the other terminal leads the current to the primary windings of the induction coil; from the coil the current goes through the breaker mechanism and then to the ground; the condenser is connected around the breaker mechanism.

Secondary Circuit:

One end of the secondary coil is attached to the ground; the other ends conducts the high tension current to the distributor arm; from there it goes to the spark plug as deter-

mined by the proper distributor segment jumps across the gap, to the ground.

MAGNETOS

A magneto contains all the elements of the ignition system previously described, and has the same primary and secondary circuits. It differs, however, in that it generates its own primary current, again by the principle of induction. There are two main methods of doing this. In both cases lines of force are furnished by permanent magnets. The first type of magneto to be discussed is that in which the charge in the number of lines of forms through the coils is accomplished by rotating the coils in the magnetic field created by the permanent magnets. The intensity of the primary current induced in this case depends to a great extent on the rate of change of flux, which varies with the speed of rotation of the coils. The coils are wound on a rotating member called the armature, and the momentary intensity of the current depends on the position of the armature, relative to the permanent magnets.

The armature used is of the shuttle type, a section of it being roughly that of the capital letter I. The vertical part of the shuttel then may also perform the function of a core and the coils are wound about it, the primary first, then the secondary. Magnetic lines of force follow the path of least resistance, and it is obvious that there will be two points per revolution of the shuttle where the lines of force passing through the core will change in direction. During the reversal of flux, there will be a point if highest primary induction, which, if utilized by opening the breaker points, will cause maximum secondary induction. It may be seen that with this type of magneto it is possible to obtain two sparks per revolution of the shuttle.

Magnetos of this character are classified as revolving shuttle type, and among them are the Bosch and Berling.

DIXIE MAGNETO

The Dixie magneto operates on a principle entirely different from the rotating shuttle type. The magnets and windings in the Dixie are both stationary, and the only rotating member is the rotary pole structure.

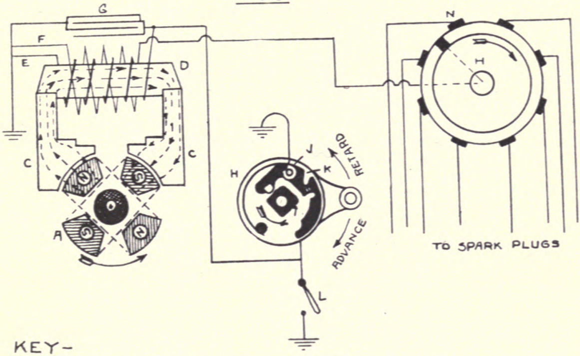
The rotary pole structure is an extension of the permanent magnets, and it rotates across the face of the field pole structure. The primary and secondary coils are wound around a core which is mounted on top of the field pole structure in such a manner as to form a path for the magnetic flux as it flows from the rotary poles. The rotary pole structure having two extensions of the north, and two of the south, arranged alternately, gives four reversals of flux through the core of the windings every revolution of the rotary pole structure. Consequently, there would be four inductions per revolution, and one spark per induction. This is a decided advantage over the rotary shuttle type which gives two sparks per revolution, and has to rotate twice as fast to do the same work.

From the above, it can be seen that the breaker mechanism would have to open and close the primary circuit four times per revolution; and the Dixie would be timed to rotate one-half the speed of a Bosch or Berling on the same engine.

Referring to the drawing on page 43, it can be seen in figure 1, that the rotary pole structure A, is in the position of maximum flux flow, and that the magnetic flux is flowing from the *north* rotating pole through the field pole structure C, thence through the field pole D, and back into the *south* rotating pole. It can be seen that a quarter revolution of the rotary pole structure A, will give a complete reversal of the magnetic flux, because the polarity would change from south to north on one side and north to south on the other side. Figure No. 2 shows a complete reversal of flux flow which was brought about by a quarter revolution of the rotary pole

DIXIE MAGNETO

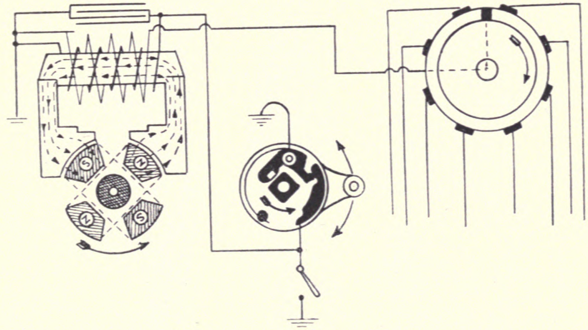
FIG. 1



KEY–

A – ROTARY POLE STRUCTURE
B – BRASS SHAFT
C – FIELD POLE STRUCTURE
D – FIELD CORE
E – PRIMARY WINDINGS
F – SECONDARY "
G – CONDENSER
H – BREAKER MECHANISM
I – CAM
J – BREAKER LEVER
K – CONTACTS
L – SWITCH
M – DISTRIBUTOR ROTOR
N – " SEGMENT

FIG. 2



structure A. As it is this sudden reversal of flux that causes the induction of current in the winding, and gives the spark. Four of these reversals coming every revolution of the rotary pole structure, will give off four sparks. It has been explained, in preceding chapters, that the primary circuit must be interrupted for every reversal of flux or induction, and in the Dixie magneto, this is provided for by a cam having four lobes, and rotating at the same speed as the rotary pole structure. The windings, condenser, breaker mechanism, distributor, etc., are clearly shown in the drawing, a study of which will enable the reader to clearly understand the Dixie principle.

TIMING

Valve Timing: It has been pointed out that there must be certain valve action during certain piston strokes, and that the valve action is controlled by the cam shaft which necessarily must turn at half crank shaft speed. It is further necessary to conform to the manufacturers' standards for exact points of valve opening and closing. The average engine used in naval aviation will conform within very close limits to the following valve timing:

Intake Valve open	TDC	15° Past TDC
Intake Valve closed	35° past BDC	50° Past BDC
Exhaust Valve open	50° before BDC	35° Before BDC
Exhaust Valve closed	TDC	15° Past TDC

From this it will be seen that the following may be assumed a good average chart for valve operation:

Intake open	10° Past TDC
Intake close	45° Past BDC
Exhaust open	50° Before BDC
Exhaust close	10° Past TDC

This may then be used for the ensuing discussion. It will be noted that valves very seldom open or close on dead centers. The distance by which a valve opens or closes before or after a

dead center is usually measured as given, in degrees of crank shaft rotation. It may also be measured, and is occasionally, in linear distance of piston travel.

The intake valve is allowed to remain open after the piston has passed bottom center, in order that a maximum charge of gas may be drawn into the cylinder. The piston moving down in the cylinder displaces space faster than the restricted area of the intake port can allow it to be relieved, and even though the piston has passed bottom center, there is still some vacuum in the cylinder, and this vacuum will continue to draw in gas as long as it exists and the intake valve is kept open until this vacuum is completely relieved.

From the closing of the intake to the opening of the exhaust there can be no valve action, since compression and power must take place and both valves must be kept closed during compression and power. The exhaust valve opens early, or before BDC, primarily to insure complete scavenging. At 50° before BDC the angularity of the connecting rod is so small that any additional work given by expanding gases would be slight. It is then better to utilize the expansion left in the gases at this part of the stroke to aid scavenging, thereby insuring its being more complete and relieving the piston of part of the work on the exhaust stroke. The exhaust valve is allowed to remain open until after TDC simply again to insure complete scavenging.

The intake valve opens at a point which will allow equalization of pressure in the cylinder.

It will then be seen that it is absolutely necessary to time the valves so that their openings and closings will be exactly in accordance with the manufacturers' specifications, since these are given for best engine running results.

In order to time the cam shaft, and thereby the valves on an engine having one cam shaft on which both exhaust and

intake cams are placed, it is necessary to accomplish the following things:

(1) *Determine the proper direction of rotation of the engine.*

This is best done by determining rotation to procure opening of the intake at about the point of exhaust closing. It may also be accomplished by determining the proper direction of rotation of water pump or propeller. In these cases it is necessary to take gear drives into consideration.

(2) *Adjust the Valve clearance.*

This must be done when the cam follower is on the low part or heel of the cam so that the valves will be finally seated. Such a condition will be sure to exist at about TDC of compression stroke. This position may be approximated by turning the engine in correct direction to the point of closing of the intake valve, then turning approximately half a revolution more.

(3) *Intake valve of No.* 1 *cylinder just opening.*

This will bring the cam shaft into its proper position or timing.

(4) *Disconnect cam shaft from crank shaft.*

Since the cam shaft is in its proper position it must not be moved further.

(5) *Place piston of No.* 1 *cylinder on Top Dead Center and number of degrees after TDC as specified by the manufacturer of intake valve to open.*

This will bring piston to point for intake valve opening.

(6) *Connect cam shaft to crank shaft.*

(7) *Check Timing very carefully.*

For quick work very often the valve clearance is adjusted for timing purposes on No. 1 cylinder only. If this method is

employed, the clearance on the remaining valves must be set and checked after timing.

It may then be seen that valve timing consists merely of making an intake valve function when the piston is at the proper position for such functioning to occur. Timing may be done on either opening or closing of either valve, but it is common pactice to use intake opening.

If there is only one cam shaft it is necessary to time on one valve only. If there are more than one cam shaft, it is necessary to time each cam shaft separately.

The angular travel of the crank shaft may be found by means of a timing disk which is fastened to the crank shaft. This is simply a disk graduated in degrees.

If, as may possibly be the case, the ignition system is properly timed to an engine during valve timing, it is necessary to be careful of the Top Dead Center used. Obviously, spark must occur at or near TDC of compression, when both valves must be tight closed.

Spark Advance and Retard:

In order to obtain maximum power, combustion should be complete and, therefore, maximum pressure generated, at top dead center. As a definite time elapses between the flashing of the spark and the completion of combustion, the spark must occur before top dead center, and the faster the engines run the further in advance of dead center it must occur. If combustion, due to a late spark, were completed after top dead center, all power would not be extracted from the gases when the exhaust valve opens, and overheating would result. If the engine is turning over slowly, the spark must be retarded, or, in other words, must occur later in the cycle, or the point of maximum pressure will occur before top dead center, and the crankshaft will receive an impulse to turn in the wrong direction, giving rise to a knock. If this occurred while cranking the engine, it would cause a back-kick. Hence the spark must be retarded when cranking. This variation in the time of oc-

currence of the spark is obtained by causing the cam to open the circuit breaker points earlier or later.

This is accomplished by moving the advance retard lever in the same direction as the rotation of the magneto shaft to obtain retarded spark and in the opposite direction to rotation to obtain advanced spark.

Magneto Timing:

Since there are two positions in which the magneto may be set, viz., advanced and retarded, it may readily be seen that there may be two methods of timing, Advanced or Retarded.

Advanced Position:

(1) *Determine direction of rotation of engine.* As given under valve timing.
(2) *Determine direction of rotation of magneto.* Usually indicated by an arrow stamped on the oil cup at the driving end.
(3) *Place piston of No.* 1 *cylinder at top dead center of compression stroke and number of degrees before TDC as specified by the manufacturer for advanced spark to occur.* This is usually from 20° to 30°. This puts the piston in position for spark to occur.
(4) *Fully advance the magneto.*
(5) *Turn distributor brush to No.* 1 *segment.*
(6) *Turn magneto shaft until points are just breaking.* This places magneto in position ready to give spark.
(7) *Connect magneto to engine.*
(8) *Find firing order of engine*—by watching any successive valve operation.
(9) *Connect distributor segments in accordance with firing order.*
(10) *Check up timing.*

Retarded position:

The same as advanced method, except for the following: In No. 3 place piston of No. 1 cylinder at TDC of compression stroke. It is always safe to assume retarded spark as occurring here. If the manufacturer specifies differently follow specifications. Some engines have retarded spark occurring a few degrees after TDC. In No. 4 fully retard the magneto, otherwise follow the advanced method. The advanced method should be used whenever possible. Only use the retarded method when there is not sufficient data to enable the use of the advanced method.

Note.—Where two or more magnetos are used they must be timed separately and so as to break at exactly the same instant. If they are not so synchronized the effect will be that of only one magneto.

EMERGENCY REPAIRS

It sometimes becomes necessary to make repairs of a temporary nature, in order to keep an engine running. This is especially true of long flights. In order to make repairs quickly and intelligently, the operator must familiarize himself with the propulsion plant of the flying-boat or plane he is operating.

A complete kit of tools and spares must be carried, and the operator should inspect this kit carefully before starting on a long flight.

When in flight the operator should pay particular attention to the various gauges, tachometer, oil and water temperature gauges, oil pressure gauge, and ampere meter. These instruments indicate at all times the working condition of the engine, and a sudden change indicated on one of these gauges is invariably an indication of trouble. Water-hose connections sometimes burst or get loose. This results in a loss of water and overheating of the engine, and would be indicated by the

water-temperature meter showing a sudden increase of temperature. Repairs can be made by fitting a new hose connection or binding the broken one with friction tape. As the water has all escaped through the broken connection it becomes necessary to use sea water. Sea water can be used in an emergency of this kind in order to get back to the base or station, and the cooling system should be thoroughly flushed with fresh water as soon as possible.

Broken water jackets can be repaired on some engines by plugging the inlet and outlet water pipes of the cylinder and disconnecting the spark plug wires. This puts the damaged cylinder out of service, and as it could not fire it would need no water circulation.

On the Liberty engine using Delco ignition, it may become necessary to start two or more engines with one battery. This may happen with one of the large flying boats having two or more engines, and is brought about by a battery becoming exhausted or broken. In a case of this kind, two or more engines can be started by connecting one good battery to the first engine to be started, and starting same. Speed this engine up to 700 r. p. m. and throw back switches *on*. The battery generator will then charge and the battery can be disconnected and used in the same manner for starting other engines.

Temporary repairs to broken gasoline pipes can be made by wrapping with tape or by slipping rubber tubing over each broken end (this rubber tubing is usually carried in the kit).

ENGINE CHARACTERISTICS

LIBERTY—12

12 *Cylinders*—Vee type angle between cylinder banks 45°.

Bore—5 inches.

Stroke—7 inches.

Cooling—Water circulated by a high speed centrifugal pump.

Lubrication—Force feed dry sump external oil reservoirs. Capacity, 13 American gallons.

Carburetion—2 Zenith Duplex model U. S. 52.

Ignition—Delco battery type.

Idling speed—650 to 800 r.p.m.

Valve timing—

Intake opens	10°	PTC.
Intake closes	45°	PBC.
Exhaust opens	50°	BBC.
Exhaust closes	10°	PTC.

Spark full advance—Occurs 30° BTC.

Spark full retard—Occurs 10° PTC.

Total spark movement— 40°

Spark plug gap— .017″

Conditions for best results—Water at outlet 170° Fahr. (Water at outlet not to exceed 200° Fahr.)

Oil temperature desired—130° Fahr. (Sometimes goes to 150° Fahr.)

Oil pressure—Varies between 20 lbs. and 50 lbs.

Generator charging rate—With fully charged battery 1.5 to 3 amperes.

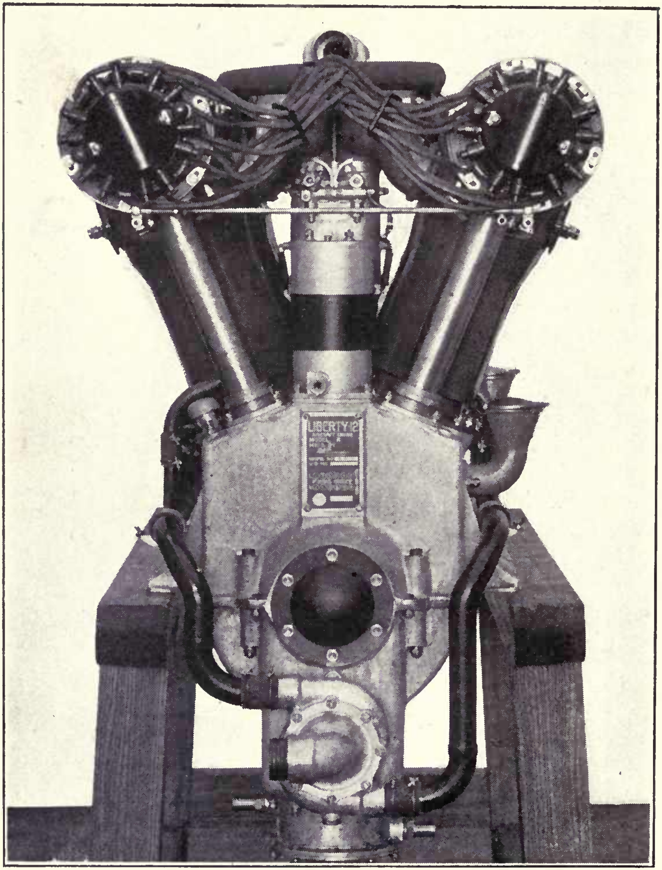
Firing order—1L-6R-5L-2R-3L-4R-6L-1R-2L-5R-4L-3R.

Valve clearance—

Intake	.014″ to .016″.
Exhaust	.019″ to .021″.

Breaker gap—All contacts .010″ to .013″.

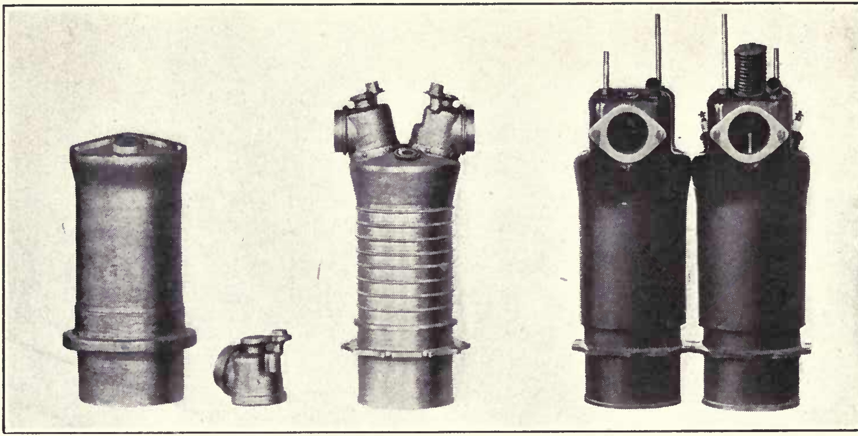
Spark plug gap—0.17″.



THE LIBERTY ENGINE—MODEL A
Timing gear end. Showing ignition heads, generator, cam shaft drive, water pump and oil pump assembly.

One of the chief characteristics of the Liberty engine is the use of a 45° angle between banks. With the ordinary twelve cylinders having an equal firing interval, the angle used is 60°. By decreasing this angle the resistance offered by the engine in flight is naturally decreased. This is a very important factor, particularly where the engine is incorporated in the fuselage itself. The use of the smaller angle also makes possible a more rigid construction, and better reinforcement of the crank case. By the use of the consequent unequal firing interval of 45°-75° the resultant sympathetic vibration produced approximates 0. In any engine with an even firing interval this vibration is found to a much greater extent and as vibration is detrimental to the molecular construction of the metals used, it may be seen the additional advantage derived. To illustrate this point more clearly: a body of troops marching across a bridge use "route step." If they were allowed to march "in step" there would be serious danger of collapse of the bridge, because of the resultant sympathetic vibration.

The construction of the cylinders of the Liberty engine follow to a certain extent the methods used by the Mercedes, Benz, and other foreign manufacturers. The cylinder sleeve itself is machined from a steel forging, the valve cages are welded on, and the water jackets, which are of pressed steel, are welded to this assembly. The cylinder itself is forged by a unique process developed by the Ford Motor Company—a piece of steel, resembling a section of boiler tubing, is so forged by means of steam presses that the finished product is sealed at the top upset to provide the semi-spherical combustion chamber, and have a metal ring providing the flange for attachment to the crank case. By the use of this process the expense of manufacture was greatly diminished over any method heretofore used, and it was possible to turn out well over two thousand forgings a day. This rough forging weighs approximately fifty-eight pounds, while the finished cylinder,



THE LIBERTY ENGINE CYLINDER

Showing the progressive stages from the first forging to the complete cylinder.

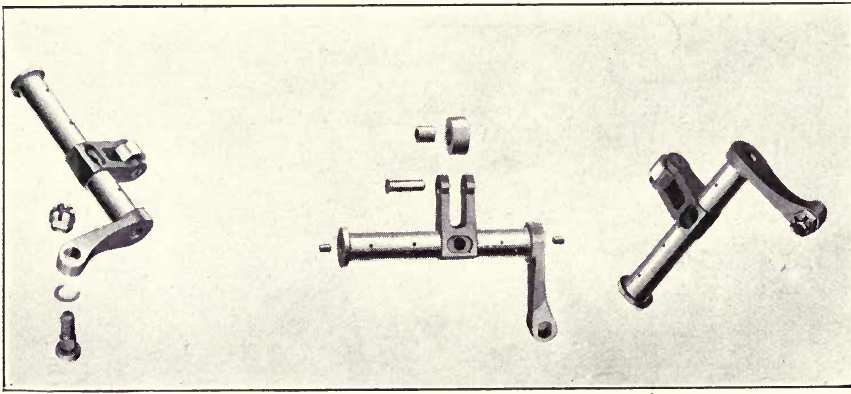
including valves and valve springs, weighs only approximately twenty pounds. From this it is possible to obtain some realization of the machining done.

The cylinder extends considerably below the holding down flange, giving increased strength to the assembly. The information of the combustion chamber is hemispherical with the valves and spark plugs located symmetrically in the head. The cylinder is upset at the combustion chamber, so that ample clearance may be afforded for the large valves used. The outside of the cylinder is flanged, so that additional cooling surface is provided.

On account of the high compression used, it is necessary to provide extremely efficient cooling. This is done by the use of a pump of large capacity (one hundred gallons per minute at maximum speed). Also the water enters the jackets at the side, causing a swirling rapid circulation. It also flows freely over the combustion chamber and around the valves. From the top of the jackets it enters jackets surrounding the intake manifolds, so that the incoming gases are heated. From these manifolds it passes through the main water heater, back to the radiator.

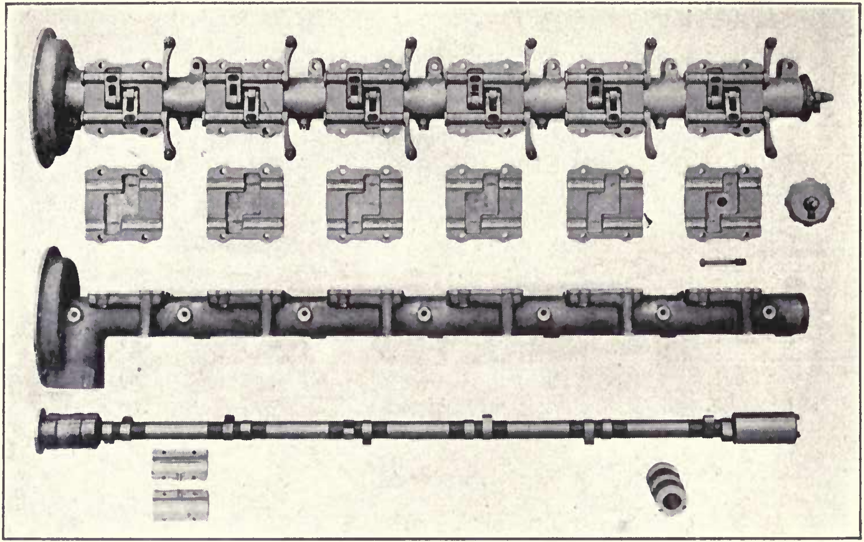
The cam shafts are of the over head type of special and improved design, being well lubricated and yet practically oil tight. They are driven by tower shafts, which derive their motion from timing gears in the crank case.

The lubrication system is essentially one of the forced feed principal. The engine is of the dry sump type. The oil being carried in outside reservoirs. It is therefore necessary to supply two oil pumps, one for delivery of oil through the system, and one for return back to the reservoirs. These two pumps are of the rotary gear type, and are both included in one assembly. The oil goes from the reservoirs to the delivery pump by gravity. From there it goes past a pressure relief valve, (regulated to fifty pounds maximum pressure) to the main oil duct which runs the length of the engine, along the



THE LIBERTY ENGINE ROCKER ARMS

Showing the unique method of adjusting valve clearance by use of a split washer.



THE LIBERTY ENGINE CAM SHAFT

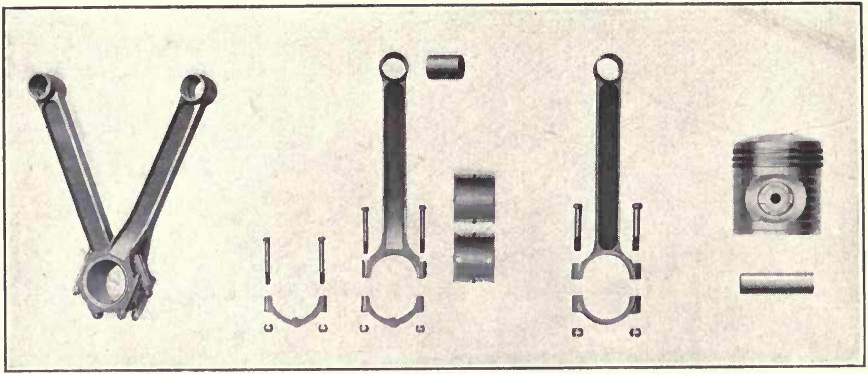
Showing the different stages of assembly.

bottom of the sump. From this duct it goes to the seven main crank shaft bearings, through leads in the webbing. Oil enters the first six crank journals and flows to the crank pins, through holes in the cheeks. Thus lubrication is provided for connecting rod bearings; cylinder walls; etc. The part of this oil not actually consumed, falls back into the sump, with the propellor end of the engine up, it flows direct to the return pump, and thence to the reservoirs. With the propellor end down it collects in a small well near this end of the sump, and goes to the return pump by means of a suction duct, provided for the purpose. Part of the oil is conducted around the main bearing at the propellor end, and goes through outside leads, to the cam shaft. It flows through these providing lubrication. From here it flows down through the cam shaft drive housings, over the timing gears, to the return pump.

There is, practically speaking, only one difference between the Liberty engines, as used by the Army and Navy. The former use a higher compression than the latter. This is accomplished by means of a dome topped piston, as against a flat-topped piston. The horse-power developed in the low compression engines, ranges 375-400. While that of the high compression is from 425-450. The weight of both engines is approximately eight hundred and twenty-five pounds (825 lbs.) and the maximum speed from 1650 to 1800.

The crank shaft used is a drop forging, having seven bearings and being two and five-eighth inches in diameter. The crank shaft bearings are carried in the webbing between the crank case and the sump; thus making a very rigid construction, and giving better constructional alinements.

The connecting rods are of the "I" beam type—twelve inches between centers. They are of the forked type, so that no offsetting of the cylinder banks is required. The left rods are forked, and the right plain. The piston pin is a seamless steel tube, and is a drive fit into the bosses of the aluminum piston. They are of the full floating type, being held in place



THE LIBERTY ENGINE CONNECTING ROD AND PISTON ASSEMBLY

Note the piston pin retainer which does away with the danger of scored cylinder walls due to the piston pin breaking loose and slipping out.

by piston pin retainers. These are small pieces of aluminum, shaped to conform with the piston surface. They are placed in the outer side of each boss, so that while the piston pin is free to move, in both the bosses and the connecting rod, its lateral motion is constrained. By this method of construction the danger of the piston pin breaking loose, and scoring the cylinder walls, is done away with.

The following paragraphs describing the carburetors used in the Liberty engine are reprinted from an article written by the Zenith Carburetor Company.

"The carburetors used on Liberty engines are of Zenith manufacture and are of duplex, or double, type, and known as their Model US-52. Each barrel is of 52 mm. inside diameter and as two carburetors are used on each 12-cylinder engine there is, in effect, one complete carbureting chamber for each three cylinders."

"As synchronism is essential, it is necessary that each carbureting chamber supplies the same amount of a fuel mixture that is itself composed of equal proportions of fuel vapor and air with any given throttle openings. Obviously, all four throttle valves must operate in unison."

"To accomplish this result it is necessary that each fuel orifice and choke tube shall deliver the same amount of fuel and air under a given suction. The choke tubes, commonly called venturi or chokes, are designed so as to offer the least resistance to passage of the air, and are therefore of a perfect stream line in section. At present, the carburetor setting for the 12-cylinder Liberty engines calls for a No. 31 choke. This means that the throat diameter, or the inside diameter of the choke at its narrowest point, is exactly 31 mm. This is checked by the use of "go" and "no go" ball gauges, and is held accurate within limits of .006"."

"The main jet sizes now used are, for the high compression Army engines, No. 140, and for the low compression Navy engines, No. 145. The jets are numbered according to

the diameter in 1.100th of a mm. of the fuel orifice, and they are calibrated and carefully gauged for size by means of actual flow of water through them from a height which is kept constant by an automatic level device in the testing tank. The testing is done automatically by an electric and clock device which causes the water passing through the jet to flow into a cubic centimeter graduate for exactly one minute, when the water is diverted, also automatically, into a drain for a period of ½ minute of time, during which interval another jet is placed in the machine for testing. From experiment and calculation it is known that a 1 40-100 mm. jet will flow 335 cu. cm. of water in one minute from a head of 1 meter. The tolerance allowable is 4 cu. cm. over and 1 cu. cm. under. The larger "over" limit is used because the graduate will not always be perfectly drained. The same method of numbering and calibrating is used in the case of the compensating jets. The present setting calls for, in the case of the Army engine, a No. 150 Compensator, and, for the Navy engine, a No. 155 Compensator."

A starting and idling device is incorporated in the construction of the carburetor which works only when the throttle valves are in nearly closed position. This device consists of the "idling tube" which is drilled at its lower and with a 1 mm. drill for the measuring of the fuel, and at its upper end, with four 1 mm. holes for the measuring of the air; and of a "priming tube" which projects down to about 1 mm. from the bottom of the "idling tube," and which forms a passage for the mixture of fuel and air to the "priming hole" which enters the carbureting chamber at the lower edge of the throttle valves. It should be noted that, as the relative position of the throttle valve and the priming hole determines the suction on the idling device, and consequently the quality of the idling mixture, the throttle valves should all be fitted within very narrow limits and that, when completely closed, the top of the valves should just cover the priming holes. If this point

is noted, it is obvious that the throttle valves will all open in unison and thus be in synchronism. The wide-open positions of the valves will take care of themselves and are, relatively, not so important as the closed positions. As a matter of fact, after the throttle valves are three-quarters of the way open, further opening will not have such influence on the power or action of the engine.

When the throttle valves are opened, the suction on the jets overcomes the suction at the priming holes, and the fuel is therefore drawn through the jets and the idling device is automatically put out of action.

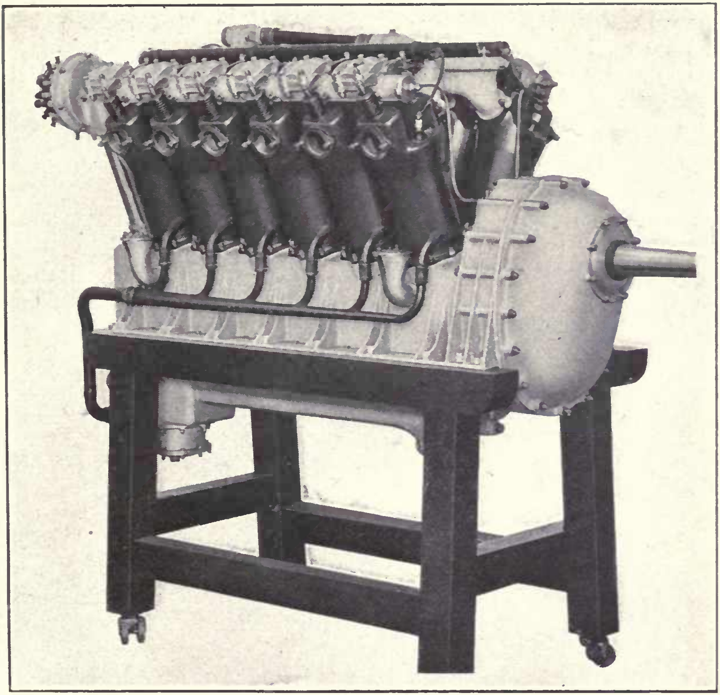
An adjustment is incorporated in the carburetor for the purpose of conserving the fuel supply by taking advantage of the lesser demand for fuel due to the decrease in air density met with in higher altitudes.

The purpose is accomplished by "putting a brake" on the fuel supply thru the jets. The carburetor fuel bowl normally has atmospheric pressure existing within it, and this pressure is reduced by placing it in communication, thru a suitable channel and adjustable valve, with the inside of the carburetor barrel, where a low pressure condition exists during the running of the engine. By thus reducing the pressure on the jets, their flow is decreased to a point where it compensates for the lesser weight of air being drawn into the carburetor, a proper air-gas mixture ratio is maintained, and wastage fuel eliminated.

LIBERTY-DELCO IGNITION SYSTEM

The ignition system as used on the Liberty engine is of Delco design, and made by the Dayton Engineering Laboratories of Dayton, Ohio. It is a battery generator system and primarilly operates on the principle of the battery system, as described previously.

The system consists essentially of six units, viz: two



THE LIBERTY ENGINE—MODEL B

Showing the incorporation of a reduction gearing enabling higher engine speeds and consequently increased Horse Power Output. The gearing keeps the propeller speed down to an efficient range.

distributor heads, storage battery, generator, switch, and voltage regulator. Both distributor heads are identical and contain the breaker mechanism, condensor, induction coil, and distributor. The distributor segments, coils and secondary terminals, are encased in Baekelite so that they are fool proof. Also the coils are protected from dampness and consequent deterioration. This Baekelite assembly fastens to the rest of the head by clamps and thumb screws which act as coil terminals. Also contained in the entire assembly are the breaker mechanism, condenser, and distributor arm.

The battery supplies the current for starting and is a four cell three volt storage type. The generator is a four pole, shunt wound, direct current machine, so arranged that at engine speeds of 650 r.p.m. and over it generates sufficient current to supply ignition and charge the battery. The voltage regulator is used so that the charging rate may be kept constant and not increase excessively due to the increase of engine speeds. It operates on the Tyrrel principle by fluctuating the generator field strength rapidly and consequently keeping the voltage output at what may be taken as a constant value. The switch assembly is a combination of two switches; one to control the left hand distributor head, which is placed on the timing gear end of the left hand cam shaft; the other to control the right hand head located correspondingly on the right hand cam shaft. The switch is so arranged as to control the circuits to each of the distributors, and generator to battery circuit. It also includes an ammeter which has proven very useful since it tells the condition of the ignition system at all times.

The ammeter shows the charging rate of the generator, or the discharging rate of the battery whenever either or both switches are on, and at all engine speeds. Each distributor is connected to give twelve sparks every two revolutions of the crank shaft, thus firing one spark plug in each of the twelve cylinders. The advantage of this is more positive and

complete ignition, providing both sparks occur at the same instant, as they must be timed to do. This also provides a larger safety factor, since the engine will run with only one spark plug in each cylinder firing, the only effect being a slight drop in r.p.m.

The breaker mechanism, instead of having only one set of breaker points, has two sets, which are arranged in parallel and termed accordingly—the parallel breakers. The advantage is again safety factor and the additional path for current flow when the points are together for an extremely short interval, as is the case at high engine speeds. Naturally two breaker points offer less resistance to the current flow than would one. The use of the safety factor is apparent in that one set of points may stick open, or become entirely inoperative for some reason, and yet the other set will carry the load and the engine will operate without hindrance; the only difference being a slightly less intense spark at high speed.

In a battery ignition system the source of current, being always constant, will cause induction to take place whenever the primary circuit is broken, regardless of the direction of rotation, as it is very often necessary, particularly when cranking by the propeller, to rock the motor. It may be readily seen that sane means be used to prevent ignition occurring, so that the danger of a back kick may be eliminated. This is accomplished by means of an auxiliary or third breaker point. This is also incorporated in the distributor, and is connected in parallel with the parallel breakers. It is so placed and timed, so that when the engine is rotated in the proper direction it will open slightly before the main points, thus causing no hindrance to the proper break. A small resistance unit is connected in series with the third breaker.

When rotation in the improper direction occurs, the main points open first and the third point remaining closed, provides a connection to the ground. Due to the resistance unit the primary current is so weakened in value that when the

third point does open the induction caused is not strong enough to produce a spark. It must be noted, however, that this does not prevent the occurrence of one spark due to cranking with the spark in the advanced position. Consequently it is possible, as in any engine, to obtain a back kick, if the spark is not retarded when starting. It is, however, impossible for counter rotation to occur to more than this extent.

The cam that operates the breakers has twelve lobes, and rotates at cam shaft speed. These lobes are spaced 22.5° and 37.5° apart. This unequal spacing is brought about by the angle between cylinder banks (45°) which causes unequally spaced power impulses, consequently, unequally spaced sparks must be delivered. The battery is a storage type having four cells, its voltage when fully charged is approximately nine volts and must never be allowed to become discharged. The battery is tested with a hydrometer syringe, and the specific gravity of the electrolyte should be 1.280 to 1.310 for a full charge. To test battery with hydrometer, lay battery on side until electrolyte has run into the top chamber, then suck it out with hydrometer. The battery is of the non-spillable type, and differs from the ordinary automobile battery only in that respect. As the generator is only intended to keep the battery fully charged, and *not* to recharge a discharged battery, a battery that shows a hydrometer reading of 1.225 or less should be taken off and charged from an external source.

The generator requires no attention except for an occasional oiling.

The regulator has one adjustment, and should not be interferred with. The charging rate of the generator is 1.5 to 3 amperes, and should only be adjusted with a fully charged battery, and by someone familiar with the regulator.

The switch contains the ignition resistance units which are connected in series with the distributors. The function of these resistance units is to control the flow of current when the engine is being started or is running slow. If the engine

is stopped and one switch is thrown on (either one), the battery, is connected to the distributor controlled by that switch. If the breaker contacts have closed, there would be a very heavy discharge of current, which would soon weaken the battery. To overcome this the resistance unit is used, and it will only allow a discharge of 4 to 5 amperes (registered on amperes meter), which is all the current necessary for ignition.

The engine is always started with one switch (either one) "on" and *both* switches should not be thrown "on" until the engine is running 650 r.p.m. or faster. With one switch on the battery is supplying the current, and the ampere meter will show a discharge; with both switches on and an engine-speed of 650 r.p.m. or faster, the generator is supplying the current, and the ampere meter will show "charge." It can be seen from the above, that with both switches on and an engine-speed of less than 650 r.p.m., the battery would be supplying the current for both distributors, and that the battery would also be discharging through the generator. The result would be a heavy drain on the battery, which would soon result in its being damaged, or completely exhausted. Conditions such as this are always indicated by a heavy "discharge" on the ampere meter and should be avoided by throwing "off" one switch.

In order that the operation of the switch may be made clear, a diagram showing three positions of the switch is shown on the preceding page.

Figure 1 shows the right switch in the position "on" for starting. The right switch moves the two blades G, and H, on and off the three contacts. These two blades are connected together. It can be seen that current will flow from the battery connected at A, through the ampere meter, then through the two blades, and out through the resistance unit (crooked line) to the right distributor connected at D.

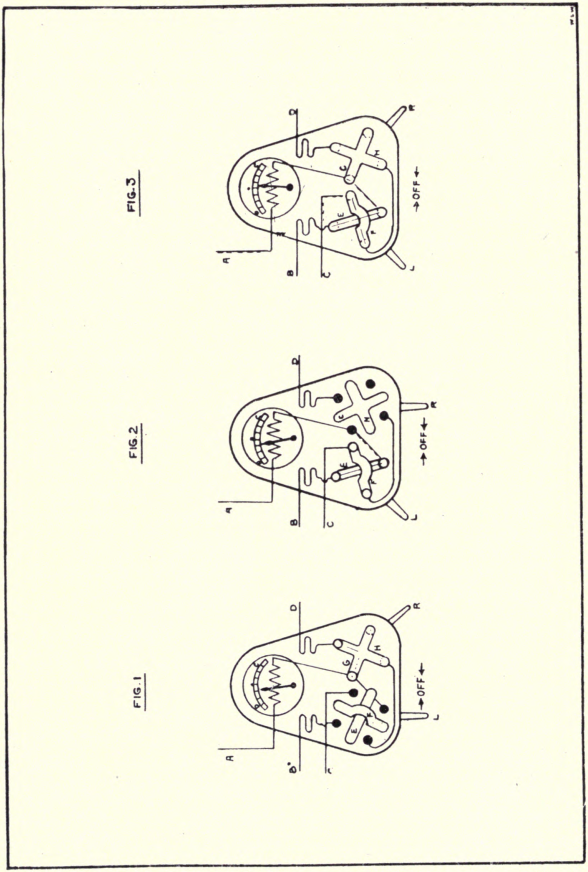
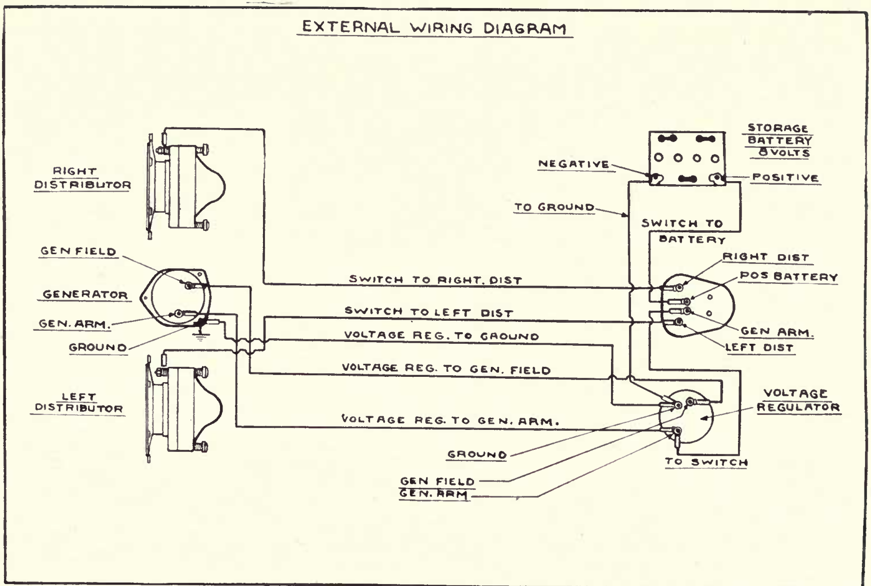


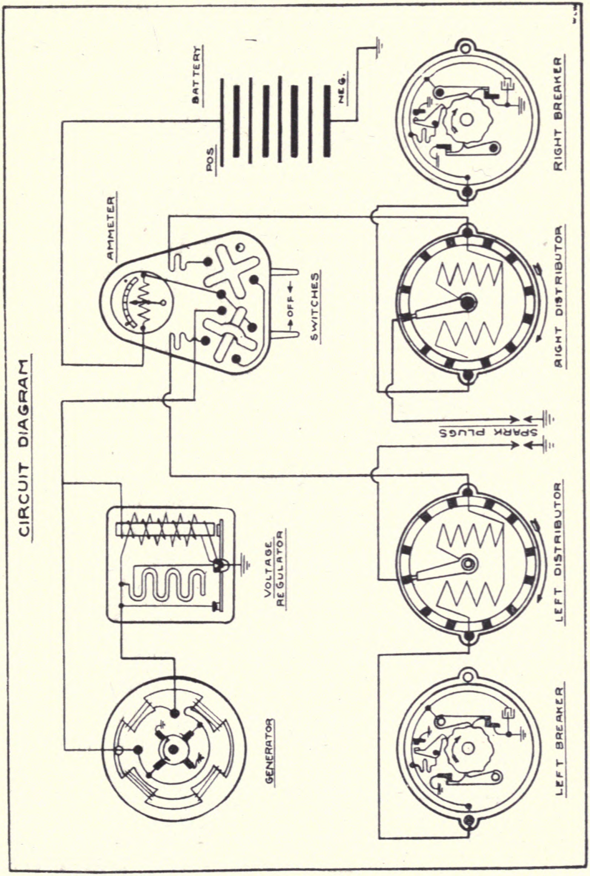
FIG. 1
FIG. 2
FIG. 3
→ OFF ←

Figure 2 shows the left switch in the position "on" for starting, and the same conditions prevail as in figure 1, except that the two blades E, and F, are insulated from each other, so that current flows through each blade independent of the other. It will be noticed in figures 1 and 2 that the ampere meter shows a discharge of approximately 4.5 amperes. The meter should always have a discharge of approximately 4.5 amperes, with engines stopped and *one* switch "on" provided the *breaker points in the distributor are closed.*

Figure 3 shows *both* switches "on," and the meter indicating "charge." This condition is indicated for engine speeds of over 650 r.p.m. as the generator is now supplying the current. The generator circuit is completed from C through the blade F to blade H, from this blade the current can be traced to both distributors and to the battery.



LIBERTY-DELCO IGNITION.



LIBERTY-DELCO IGNITION.

ORDER OF TEARDOWN

U. S. N. LIBERTY MOTOR SCHOOL

1. Distributor head and high tension wire conduit.
2. Drain all oil.
3. Distributor mechanism.
4. Oil pipes.
5. Camshaft assembly.
6. Generator.
7. Mark carburetor and intake headers.
8. Water pipes and hose.
9. Breathers.
10. Carburetors.
11. Intake headers.
12. Propeller hub.
13. Cylinders.
14. Oil pump assembly and pump cover.
15. Water pump assembly.
16. Two camshaft drive shaft gear assembly.
17. Oil pump driving gears.
18. Water pump driving gears and shaft assembly.
19. Piston pin retainers.
20. Pistons.
21. Upper half crankcase.
22. Crank assembly.
23. Connecting rods and thrust bearing.

NOTE: Each part to be thoroughly oiled to resist rust, and each part (where there is opportunity of mixing up) to be tagged.

TEARDOWN

U. S. N. LIBERTY MOTOR SCHOOL

1—DUAL IGNITION SYSTEM:

(*a*) Each distributor fires one plug in each cylinder throughout entire cylinders.

(*b*) Right distributor fires plugs on gear side of cylinder while the left fires the propeller side.

(*c*) Disconnect high tension conduit which is attached to outlet water header by cap screws with no washers.

(*d*) Remove the twelve insulated wires fastened to spark plugs, being careful not to spring ball-clips. Rubber ferrules on end, must be in perfect condition to assure perfect insulation.

(*e*) Remove distributor heads held by wire clips along with the conduit. Care should be taken to bind the brushes with a rag or rubber band to prevent any breakage.

2—CAMSHAFT HOUSING ASSEMBLIES:

(*a*) Remove distributor tie rod found in upper holes with boss down.

(*b*) With spanner wrench remove collars on camshaft housings. A felt washer should be inserted in each collar to prevent oil leakage.

(*c*) Loosen castle nuts on the twelve studs of each camshaft housing. Plain washers are found under each nut.

(*d*) Disconnect oil pipes leading to camshaft before removing camshaft assemblies which are marked either right or left.

(*e*) Male splines on jack-shaft marked by a groove in one tooth.

(*f*) Female spline carried two niches on collar. Both splines must coincide for timing.

3—GENERATOR:

(*a*) Held by three castle nuts on studs. Plainwashers. Oil paper gaskets are found between generator pad and seat.

(*b*) Only one bearing in generator.

(*c*) Power connections not marked.

(*d*) Splines must fit closely to prevent any back lash (come out rather hard).

4—CARBURETORS:

(*a*) Unfasten carburetor tie-rod. Purpose of rod to make carburetors work simultaneously.

(*b*) Watch taper pins that lock tie-rod.

(*c*) Be careful of pins. Easily lost.

(*d*) Two copper asbestos washers separate each carburetor from manifold.

(*e*) Although interchangeable, mark each carburetor propeller end and gear end.

(*f*) Each carburetor held by two anchor bolts with plain washer fastened to hot water intake header.

5—HOT WATER INTAKE HEADER:

(*a*) Held by four castle nuts with washers at each end, having also two oil paper gaskets.

(*b*) This parts, with carburetor, removed practically at the same time, holding one in each hand.

6—MANIFOLD OR INTAKE HEADERS:

(*a*) Four in number, each held by six studs, castle nuts and washers, paper gaskets between each.

(*b*) Each manifold stamped on exhaust port flange—propeller end R. or L. and gear end R. or L. as the case may be.

(*c*) Remove that manifold with with smallest bearing surface first. Found hire to be right side.

(*d*) Inspect manifolds for loose cores which rattle.

7—WATER SYSTEM:

(*a*) Remove both outlet water pipes from pump. Right side is longer than left.

(*b*) Remove inlet water headers; both pipes are interchangeable (hose hands).

(*c*) Remove outlet water pipes of cylinders. Loosen all hose bands attached to cylinder.

(*d*) Three flanges attached to each manifold and held there by two cap screws through each flange having driller heads (paper gaskets between manifolds and each flange).

(*e*) Centrifugal water pump held by four studs with castle nuts. Paper gaskets separate pump pad and seat.

(*f*) Pump intake points to the left, plugged hole found at the bottom.

8—BREATHERS (CRANKCASE):

(*a*) Held by two studs washers and castle nuts, has paper gasket between, also baffle plate screen.

(*b*) On propeller end the three way distributor for oil fastened by two castle nuts, washers and has an oil paper gasket.

9—CYLINDERS (12):

(*a*) Start from gear or propeller end and remove flange nuts between each cylinder. Six other castle nuts serve to hold skirt flange to cylinder pad.

(*b*) Paper gaskets between cylinder pads and flanges are cut to cover three cylinders.

(*c*) Remove one spark plug before pulling cylinder off piston to relieve vacuum.

10—PISTONS:

(*a*) Bind studs at base of cylinder pad to prevent scratching of pistons.

(*b*) With pliers remove *piston pin retainers.*
(*c*) Drive out piston with brass plug, pounding it gently.
(*d*) Piston pin should only be driven far enough to clear pin housing.
(*e*) Each piston is marked right or left and its numerical position.
(*f*) Allow rings in grooves to remain untouched.
(*g*) Rings are common split type with two right and one left. The splits being set at 180 degrees apart.
(*h*) While removing piston pin, hold piston firmly so as not to throw connecting rods out of line.

11—GENERATOR AND CAMSHAFT ASSEMBLIES:

(*a*) Remove gear case cap held by six cap screws drilled for wiring, no washers.
(*b*) Remove jackt shaft assemblies held by four studs and castle nuts.
(*c*) Should have a paper gasket between crank case and pad.
(*d*) Each shaft marked right or left on the beveled gear.
(*c*) Ball race retainers in assembly.
(*f*) These shafts must be removed before generator shaft. as gears of former prevent removal of latter.

REMOVE GENERATOR DRIVE SHAFT:

(*a*) Duty: to drive generator and two jack shafts.
(*b*) Construction: With key-way in shaft for jack shaft gear and two spacing sleeves to hold it where it belongs.
(*c*) Bevel gear has twenty-two teeth.

12—TIMING:

(*a*) When No. 1 and No. 6 are 10 degrees past dead center, splines should be placed in line with center of cylinder.

13—REMOVAL OF LOWER CRANKCASE:

(*a*) Loosen fourteen nuts on anchor bolts, a plain washer is found beneath each.

(*b*) Turn crankcase over allowing an anchor flange to rest on wooden blocks mounted on frame.

(*c*) Remove two through bolts on each end of base. Also two anchor bolts nuts were found at propeller end and removed. Remove oil pump held by ten castle nuts with washers. A paper gasket found between.

(*d*) Remove fifty hexagon head holding upper and lower crankcases together.

(e) Lift off lower part of crankcase.

14—REMOVAL OF SPOOL GEAR:

(*a*) Loosen set screw which holds assembly in place.

(*b*) With case upright drive assembly through.

(*c*) Upon measuring it it is found to be tapered .0007″ over a distance of 2½″.

15—FORK AND PLAIN END CONNECTING RODS:

(*a*) End play of connecting rod allowed .006″, found to be as great as .016″.

(*b*) Babbitt metal bearing surface on fork rods—bronze on plain end.

REASON:

(*c*) Plain end rod is removed first by turning shaft to allow it to let go easily upon removing nuts.

(*d*) Forked rods followed, care being taken to place both halves of bearing surface as they originally were.

16—UPPER HALF CRANKCASE:

(*a*) Ispect bearing surfaces—high spots shows up bright (should be a lead color throughout).

(*b*) Watch studs for loosening up.

(*c*) Care should be taken to find any cracks or sand holes.

CRANKSHAFT INSPECTION:

(*a*) Inspect crank pins and main bearings for any scratches or rough spots.
(Crocus cloth will remove any slight scratches.)

(*b*) Teeth of driving gear on gear flanges should be perfect and not chewed up.
(Pricked punched 12 degrees 30′ past center for timing purposes).

17—CAMSHAFT ASSEMBLY:

(*a*) Remove the six plates holding rocker arms in place, held by 3 hexagonous bolts and plain washers.

(*b*) Withdraw bearing retainers which are set screws used to hold bearings in place.

(*c*) Remove oil cap on gear end with a spanner wrench.

(*d*) Remove 6 hexagonous nuts which hold distributor flange in place.

(*c*) Withdraw camshaft with bearings attached.

(*f*) Split bearing surface held by set screws—bearings are aluminum throughout except at gear end, which is a bronze bearing.

HISPANO SUIZA

MODEL "A"

8 *Cylinders*—Vee type. Angle between cylinder banks 90°.
Bore—4.72 inches. Stroke 5.11 inches.
Horse-power—150 at 1,450 r.p.m.
Cooling—Water circulated by a centrifugal pump.
Lubrication—Force feed.
Carburetion—Zenith Duplex Model 48 D. C.
Ignition— 1 Exciter magneto.
2 Dixie magnetos Model 800.

Valve Timing—

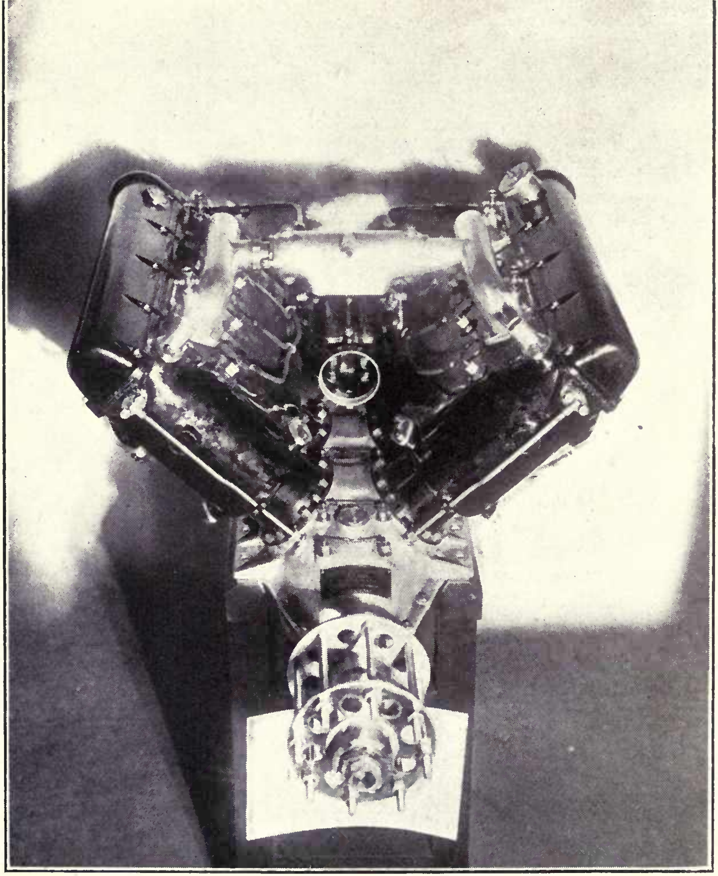
Intake opens	10°	PTC.
Intake closes	50°	PBC.
Exhaust opens	45°	BBC.
Exhaust closes	10°	PTC.

Spark occurs—20° 20′ BTC.
Conditions for best results—Water at outlet 165° to 175° Fahr. Oil temperature 130° Fahr.
Firing order—1L-4R-2L-3R-4L-1R-3L-2R.
Oil pressure—When fitted with a relief valve can be varied and is usually about 60 lbs. per square inch.
Valve clearance—.0787″.
Breaker gap— .020″.
Spark plug gap—.020″.

Two of the oustanding features of this engine are the cylinder construction, and cam action.

There are two blocks of four cylinders each, here again the steel sleeve is used. These sleeves are threaded on the outside, and four of them screwed into an aluminum casting which forms the water jacket. This gives a very light assembly and one which lends itself particularly well to stream lining.

The cam shafts are driven in practically the same way as on the Liberty, but no rocker arms are used. The valve stems are fitted with circular steel pieces which screw into them,



THE HISPANO SUIZA ENGINE
MODEL XE—300 H. P.

Showing the stream line effect obtained by the *en bloc* construction of the water jackets and the method used in housing the cam shafts. The constructional features of this model are very similar to all other models of the same engine.

against the action of the valve spring. These are called mushrooms, and the valve clearance is adjusted by screwing these in or out. The cam shaft is held on the top of the cylinder blocks, by three bronze bearings. The cams themselves act direct on the mushrooms, so that there is absolutely no lost motion. There is an almunium cover which encloses the cam shafts, and again very good stream lining is accomplished.

Each block of cylinders, after assembly, are given several coats of enamel, both inside and out, each coat being thoroughly baked on. The lower end of each cylinder projects, and has a flange, by means of which the blocks are fastened to the crank case.

The pistons are ribbed aluminum castings, provided with four rings each, in two grooves at the top. The piston pins are hollow, and are made of alloy steel—case hardened. They are held in the piston bosses by means of a single long set screw, which passes entirely through them.

The crank shaft is of the regular four-cylinder type, that is, having four throws, 180° between throws. It is of chrome nickel steel and provided with four bearings of the regulation bronze backed, babbit lined type. In addition to this there is an annular ball bearing at the cranking end. A double row ball thrust bearing is located at the propeller end. The crank shaft is bored hollow for lightness and for oiling.

The connecting rods are made of heat treated alloy steel, and are tubular in section, they are of the forked type, as in the Liberty, and carry a bronze bushing in the upper end. The crank shaft bearings are carried in the webbing of the crank case and sump, as in the Liberty. The sump is fastened to the crank case by bolts running through the webbing and also by a series of bolts around the outer edges. All joints are lapped, that is; no gaskets are required.

Lubrication is of the force feed type. Pressure is provided by a sliding vein eccentric pump. Oil is carried in the sump. The pump is mounted in the sump, directly below the crank

shaft gear. From the pump the oil goes through a removable screen filter, to the main oil duct, from this, to three of the main bearings, thence through the hollow crank shaft, to the four crank pins, lubricating the connecting rod bearings, and by spray, the piston pins, cylinder walls, etc. Oil is led up to, and around the fourth main bearing, from there it goes through outside leads, to the hollow cam shafts. It passes through these, lubrication being provided by a small hole in each cam surface. From the cam shafts it returns to the sump, passing through the cam shaft drive housings, and over the timing gears. It also lubricates, on its return, the crank shaft ball bearings.

Ignition is provided by two 8-cylinder type Dixie magnetos, firing one spark plug in each cylinder. One magneto is driven from each of the two vertical shafts. Small bevel pinions mesh with bevel gears on each magneto shaft. No packing is necessary to prevent loss of oil at these points. The oil is prevented from escaping by grooves out in the housings. The magnetos are of the set spark type, ignition occurring at 20° 20′ before T. D. C. For this reason it is necessary to provide a distributor which has two brushes, one for running ignition, the other for starting. When starting ignition is provided by a separate hand exciter, this gives a shower of sparks to the second on starting brush. This, in effect, is the same as a greatly retarded spark. Before starting it is well to turn the engine over a few times, with all ignition off, in order that a good charge may be taken into each cylinder.

For use on sea planes, a geared down hand crank is provided. In this event the exciter is geared to the starting crank.

Carburetion is provided by a double jet Zenith carburetor model No. 48 D. C. It is very similar in construction and operation to the Model U. S. 52, used in the Liberty. The intake manifold is water jacketed and runs crosswise between the cylinder blocks.

Cooling is provided by means of water circulated by a centrifugal pump, which is located at the cranking end of the engine, under the sump.

CURTISS

MODEL OXX6

8 *Cylinders*—Vee type. Angle between cylinder banks 90°.
Bore—4.25 inches. Stroke 5 inches.
Horse-power—100, at 1,400 r.p.m.
Cooling—Water circulated by a centrifugal pump.
Lubrication—Force feed.
Ignition—Two Dixie magnetos.
Carburetion—Zenith Duplex.

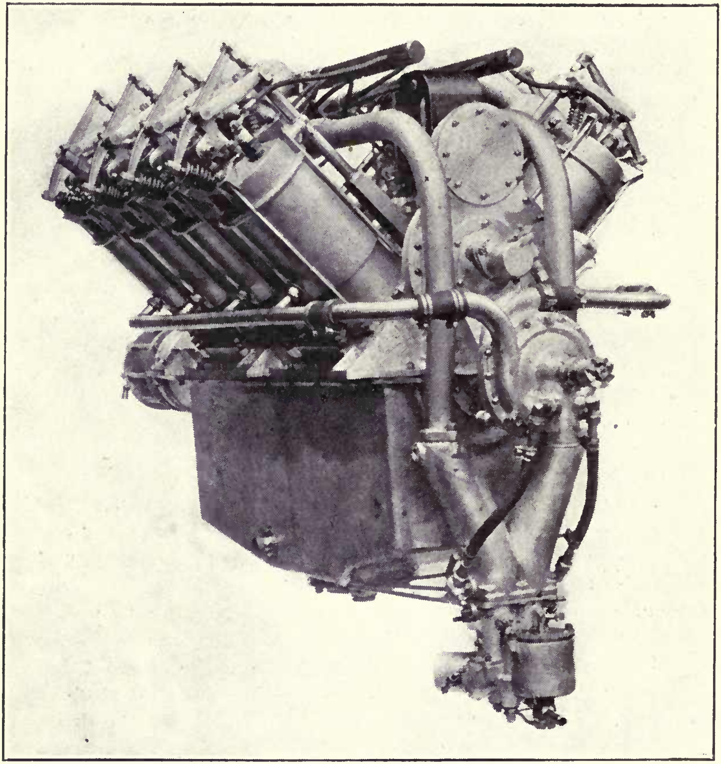
Valve Timing—	Intake opens	1/16″	PTC.
	Intake closes	1/2″	PBC.
	Exhaust opens	13/16″	BBC.
	Exhaust closes	1/32″	PTC.

Ignition occurs—Full advanced BTC.
Firing order—1-2-3-4-7-8-5-6-.
Valve clearance—.010″.
Breaker gap— .020″.
Spark plug gap—.020″.

The Curtiss O X and O X X engines are probably the most widely known and used of any in the American field. The O X is the army type and is of four inch bore and five inch stroke, while the O X X or Navy type differs only in that its bore is four and one-quarter inches.

The cylinders are steel sleeves surrounded by water jackets of Monel metal. They are constructed separately and fasten to the crank case by means of a flange, secured by studs, and also by four long studs which extend the height of the cylinder and fasten to a bracket at the top.

The engine is provided with one cam shaft, located in the crank case. The valves are located in the heads of the cylinders, the cam action being conveyed by the rocker arms, and push rod method. As applied to this model engine, the particular valve action may be called characteristic. The exhaust valve is operated in the regular manner as applied to an action of



THE CURTISS MODEL OXX ENGINE

Showing the Push and Pull Rod type of valve operating mechanism and general assembly. Note the location of the carburetor which facilitates gravity feed.

this type. In other words, when the high point or toe of the cam is up, the push rod rises and the rocker arm forces the valve off the seat. It is the operation of the intake valve which differs from conventional practice. It may be said to be operated by the pull method. The intake cam is split, being on either side of the exhaust cam, the intake cam follower is held on the cam surface constantly by spring action. There is a hollow rod surrounding the exhaust push rod. The lower end of this rod rides on the intake cam follower while the upper end is attached to the intake rocker arm. By spring action, which is very strong, the intake valve is forced off the seat when the cam follower is on the low point or heel of the intake cam. When it is on the toe of the cam, the rocker arm is held up, away from the valve stem, and the valve is closed. The greatest advantage of this valve action is economy of space.

The pistons are aluminum castings, and the hollow steel piston pins are secured by a set screw in one piston boss.

The crank shaft has four throws 180° apart, and is supported by five main bearings of the bronze backed babbit lined type. Half of each bearing is carried in the webbing of the crank case while the other half is carried in a bearing cap which is bolted to the crank case webbing, thus securing the crank shaft. This construction makes possible the dropping of the sump, without interfering with the support of the crank shaft.

The connecting rods are heated treated drop forgings of the I section type. They fasten side by side on each crank pin. It is therefore necessary to set one bank of cylinders ahead of the other.

The lubrication system is of the forced feed type. The sump is the reservoir and carries a sight gauge, and is so constructed that its center is always the lowest point. Two baffle plates are provided, which slope from the ends of the sump towards the center, and leave a three-quarter inch opening at that point. This opening extends the width of the sump. A

rotary gear pump is located in the low point of the sump. Oil from this goes to the hollow cam shaft, lubricating its bearings, thence through leads to the crank shaft bearings, through the hollow crank shaft, to the crank pins, lubricating the connecting rod bearings, and by spray the piston pins, cylinder walls, etc. The timing gears and thrust bearing are lubricated by spray. A pressure relief valve is located in the line. On returning, oil flows over the baffle plates and into the sump.

Ignition is provided by two 8-cylinder Dixie magnetos, located at each end of the crank case, between cylinder banks. Each magneto fires are spark plugs in each cylinder. They are provided with an advance-retard lever.

Carburetion is provided by a Zenith double jet carburetor, operating on the regular Zenith principle. It is located at the timing gear end of the engine, below the sump. The gases are conducted to the cylinders by means of long manifolds which are water jacketed at the lower ends.

The cooling system is of the ordinary type, water being circulated by a centrifugal pump which is located at the timing gear end of the engine, on a level with the crank shaft.

MATERIALS OF CONSTRUCTION

The following is given, as an outline, setting forth briefly, the general types of material used in the construction of the present day aviation engine.

Cylinder: Cast iron is sometimes used where economy of weight is not so essential. When it is used the water jackets are ordinarily cast integral with the cylinders.

Where economy of weight is important, a sleeve of heat treated alloy steel is used. With this type of construction the water jacket is made of pressed steel, and welded on, as in the Liberty, or the sleeve is fitted in an aluminum block, as in the Hispano Suiza.

Piston: Aluminum, cast iron and semi-steel are used. The

first is the most common, not only on account of lightness, but because of its better heat conductivity.

Piston pin: Drop forging of alloy steel, hollowed out, heat treated, and case hardened.

Connecting rod: Drop forging of alloy steel, often of chrome nickel composition, usually of "I" beam action and machined all over.

Piston Rings: Cast iron, used because it is softer than steel, and will not scratch the cylinder walls.

Valves: Drop forgings, usually of Tungsten steel, and heat treated. The presence of Tungsten gives steel the power to withstand enormous strains, even up to cherry red heat.

Crank Shaft: Drop forging of chrome nickel steel, heat treated and machined all over. The presence of chromium enables steel to withstand the succession of hammer like blows, while nickel increases the tensil strength.

Cam Shaft: Drop forging of heat treated alloy steel, with cams forged on the shaft and their surface case hardened.

Crank case and Sump: Aluminum castings, ribbed for strength, and to provide bearing surfaces.

Bearings: Usually bronze backed, Babbit lined. Babbit is a metal composed of antimony, lead and tin, and has a low melting point. Used at friction points, so that if heat becomes excessive, the Babbit will melt and prevent injury through seizure.

Bushings: Usually bronze. Used at points of wear, so that they may be easily taken out and replaced, without the necessity of providing large and expensive parts.

TROUBLE CHARTS

Trouble	Symptom	Cause	Remedy
Carburetion	No gas	Stopped up line	Clean out line.
		Lack of pressure	Apply more.
		Stopped up vent hole	Clean.
	Mixture too lean.	Water in gasoline	Clean out drains.
		Totally or partially plugged compensator or jets	Clean out.
		Compensator too small Main jet too small Venturi of too large internal diameter	Replace with one of proper size.
		Leaky intake manifold	Repair or replace.
	Mixture too rich.	Bent, sticking or improperly seated needle valve	Replace or correct.
		Leaky float	Replace or patch.
		Compensator too large Main jet too large Venturi of too small an internal diameter	Replace with one of proper size.
Magneto	No spark	Faulty switch	Repair or replace.
		Ground wire shorted	Tape or replace.
		Shorted condenser	Replace.
		Burned out coils	New magneto.
		Broken breaker point spring	Replace.
		Broken distributor arm or brush	Replace.
		Broken brush spring	Replace.
		Broken or shorted connections	Replace.
	Weak spark	Faulty breaker point adjustment	Adjust.
		Dirty or pitted breaker points	Clean.
		Dirty distributor	Clean.
		Faulty condenser	Replace.
		Out of time internally	Time or replace magneto.
		Weak magnets	Remagnetize or replace.

Indication	Symptom	Cause	Effect	Remedy
Failure to start	Carburetion	Gasoline supply shut off, stopped or exhausted..	Failure to run, possibly one or two intermittent explosions or back fire in carburetor..........	Find out by flooding and correct.
		Mixture too lean........		See under Carburetion
		Mixture too rich........		See under Carburetion
		Engine flooded with too much gas............		Turn over backwards with switch and gasoline off.
		Engine extremely cold...		Prime.
	Ignition	Switch off...............	Failure to run..........	Turn on.
		Switch broken..........	Failure to run..........	Disconnect ground wire.
		Failure to give spark....	Failure to run..........	See under Magneto.
		Weak spark............	One or two explosions but failure to continue running	See under Magneto.
Missing or irregular running	Carburetion	Air leak between carburetor and engine......	Low or fluctuating r.p.m. Surging of engine. Back fire in carburetor. Hissing	Test with oil, repair or replace.
		Incorrect mixture.......	Surging back fire or after fire. Low or fluctuating r.p.m.............	See under Carburetion
	Ignition	Dirty spark plugs.......	Skipping — surging—low or fluctuating r.p.m....	Clean.
		Spark plug gap improperly set..............	Skipping — surging—low or fluctuating r.p.m....	Adjust.
		Defective or broken spark plug	Loss of power, failure to develop r.p.m.........	Replace.
		Disconnected secondary wires	Failure to fire cylinders with those wires disconnected	Connect.
		Weak spark............	Surging fluctuating r.p.m.	See under Magneto.

TROUBLE CHARTS—Continued

Indication	Symptom	Cause	Effect	Remedy
Missing or irregular timing	Loss of compression	Improper valve clearance	Hissing, loss of power—low r.p.m.............	Adjust.
		Sticking or poorly seated valves	Hissing, loss of power—low r.p.m.............	Clean or grind in.
		Blown gasket...........	Hissing, loss of power—low r.p.m.............	Replace.
		Open or defective petcock	Hissing, loss of power—low r.p.m.............	Close or replace.
		Piston rings worn or broken	Loss of power, white oil smoke carbon, low r.p.m.	Replace.
		Piston ring slots in line..	Loss of power, white oil smoke carbon, low r.p.m.	Adjust.
		Cylinder wall scored.....	Loss of power, white oil smoke carbon, low r.p.m.	Lap in new cylinder.
		Piston scored allowing blow by..............	Loss of power, white oil smoke carbon, low r.p.m.	Lap in new piston.
		Broken valve spring or key	Loss of power, drop in r.p.m.	New spring or key.
Lack of power	Carburetion	Improper mixture.......	Low r.p.m.............	See under Carburetion
	Ignition	Weak spark............	Low r.p.m.............	See under Magneto.
	Compression	Weak compression.......	Low r.p.m.............	See under Missing or Irregular Running, Loss of Compression.
	Overheating	Lack of water...........	Temp'ture above normal.	Add water (salt water if necessary).
		Leak in water line or jackets	Temp'ture above normal.	Patch if possible—add water.
		Broken water pump.....	Temp'ture above normal.	Repair if possible—if not, fly by easy stages.

Indication	Symptom	Cause	Effect	Remedy
Lack of power	Overheating	Failure of oil to circulate.	Drop in oil pressure.....	Clean out and repair system.
		Lack of oil.............	Rise in temperature.....	Supply oil.
			Wavering and drop of pressure, followed by rise in temperature....	Supply oil.
		Broken pump, ducts, etc..	Drop in oil pressure, followed by rise in temperature	Patch up or replace.
Overheating...	Carburetion	Improper mixture.......	Rise in temp., loss of r.p.m.	See under Carburetion
	Ignition	Spark not fully advanced.	Rise in temp., loss of r.p.m.	Advance.
	Compression	Incorrect valve timing...	Rise in temp., loss of r.p.m.	Re-time.
		Carbon deposit..........	Rise in temp., loss of r.p.m.	Re-time.
	Cooling and oiling	See under Lack of Power	Overheating	Clean out carbon.
Back fire in carburetor..	Carburetion	Too lean a mixture......	See under Carburetion.	
		Air leaks in carburetor...	Results in too lean a mixture.	
	Ignition	Spark plug wire crossed..	Loss of power, drop in drop in r.p.m..........	Replace wires.
	Compression	Intake valve improperly seated	Loss of power, drop in drop in r.p.m..........	Adjust valve.
Gradual stoppage	Carburetion	Gasoline supply exhausted or stopped up..........	Backfiring—drop in r.p.m.	Clean or refill.
	Lack of oil.......	Pistons expanding and seizing	Drop of oil pressure, rise in temperature........	Refill with oil.
	Lack of water....	Pistons expanding and seizing	Drop in oil pressure, rise in temperature........	Refill with water.

TROUBLE CHARTS—Continued

Indication	Symptom	Cause	Effect	Remedy
Sudden stoppage	Ignition	Failure to supply spark..	See under Magneto.	
Vibration	Loose parts......	Propeller loose or out of line	Knocking or flutter.....	Tighten or relieve.
		Loose connecting rod, piston pin.............	Knocking, loss of power.	Tighten part.
		Loose bearings..........	Knocking, loss of power.	Adjust or replace.
	Irregular running or missing.....	(See under Missing or Irregular Running)		
	Pre-ignition	Spark advanced too far..	Knocking, loss of power.	Retard.
		Carbon deposits and overheating	Knocking, loss of power.	Clean out.
	Engine not bolted down tight.....	Faulty bolts, nuts ore threads	....	Tighten or replace.
Failure to stop	Ignition	Ground wire loose or broken	....	Adjust or replace.
		Switch defective........	....	Adjust or replace.
		Overheating	....	Idle motor before cutting switch.

INDEX